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NEW ZEALAND

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ROOT DEVELOPMENT IN SOME COMMON NEW ZEALAND PASTURE PLANTS

V. THE EFFECT OF DEFOLIATION AND ROOT PRUNING ON COCKSFOOT (*Dactylis Glomerata*) AND PERENNIAL RYEGRASS (*Lolium Perenne*)

By W. A. JACQUES and D. B. EDMOND, Massey Agricultural College, Palmerston North

(*Received for publication, 9 April 1951*)

Summary

(1) In an endeavour to assess the harm done to grassland by overgrazing, particularly in the periods of slow grass growth, the herbage of cocksfoot and perennial ryegrass plants was subjected to three levels of cutting at weekly and fortnightly intervals. One half of the plants had the new roots pruned off each week and the other half was left to develop the full root system.

(2) Weights were taken of the herbage removed and a record kept of the numbers of roots excised.

(3) Statistical significance was determined for all treatments.

(4) The stimuli that caused the responses to the different treatments are discussed.

(5) For Top Growth the order of the yields was as follows:

(*a*) Cocksfoot > Certified Perennial Ryegrass > Uncertified Perennial Ryegrass.

(*b*) Fortnightly cutting > Weekly cutting.

(*c*) 2-in. height of cutting > 1-in. height > ½-in. height.

(*d*) Non root pruned > Root pruned (these differences being significant wherever they occurred).

Solving for components of variance gave the variants the following order of importance:

Root pruning > Height of cutting > Frequency of cutting > Species.

There was an initial stimulus to top growth lasting about two weeks which appeared to be due to top treatment as it was most pronounced where the cutting was most severe. There was another stimulus lasting for a further three or four weeks probably due to root pruning.

In general the more lenient top treatments were associated with earlier spring growth and with better growth on into the summer.

(6) For Root Numbers the order was as follows:

(*a*) Certified Perennial Ryegrass > Uncertified Perennial Ryegrass > Cocksfoot.

(*b*) Fortnightly top cutting > Weekly top cutting.

(*c*) 2-in. top cut > 1-in. top cut > ½-in. top cut (these differences being significant wherever they occurred).

Solving for components of variance gave the variants the following order of importance:

Height of top cut > Species > Frequency of top cut.

Root initiation appears to be seasonal, the greatest activity being from mid-winter to late spring, with least activity in the summer. Seasonal fluctuations are greatest in certified perennial ryegrass, and least in cocksfoot. A terminal count of "crown roots" on plants which were not root pruned throughout showed similar trends in numbers to the above save that the species order was:

Cocksfoot > Uncertified Perennial Ryegrass > Certified Perennial Ryegrass.

(7) There was differential growth of roots and tops. Root initiation proceeded apace while top growth was slow. Commencement of spring top growth coincided with decline of root initiation.

INTRODUCTION

For effective grazing, grass has a maximum and minimum length of leaf; grazing beyond or below these limits decreases the yield of nutrients per acre to the grazing animal. The seasonal nature of grass growth makes difficult a close relationship between the length of leaf and the animal grazing intensity throughout the whole year. Spring and early summer flushes of grass growth cannot usually be controlled adequately by the normal complement of grazing stock. On lowland farms, at least, the surpluses are cut and stored as fodder for the lean periods in summer and winter. Farming systems are arranged to take advantage of the periods of high herbage production from pasture, and to ensure the better feeding and increase in the numbers of the animals grazing them, without deterioration in the sward. However, the authors think that considerable harm is done to grassland by overgrazing, particularly in the periods of slow grass growth. The experiments described in this paper were made to investigate the reactions of three grasses to different severities of leaf removal, while an attempt was made to follow the seasonal growth of their root systems by observing the initiation of new crown roots. The effect of soil moisture on the root initiation in grasses was also noted.

The trial was laid down on an area at Massey Agricultural College in March 1948, and was concluded in February 1949.

REVIEW OF THE LITERATURE

The growth of grass is a multi-conditioned metabolic process. Blackman[1] in 1905 stressed the difficulty of evaluating exactly the effects of changes in a single factor upon a multi-conditioned metabolic process, due to interactions with the other factors effecting metabolism. Thus, while it appears unwise to consider a specific phase of growth without regard to the other phases, this review has, for convenience and clarity, been divided into eight arbitrary divisions based on the major phase studied.

(1) *Seasonal growth of grasses*

As grass grows in a seasonal manner, the amount of seasonal growth of herbage can be modified by cutting or grazing treatments. Frequency and severity of defoliation have been the factors most often considered.

(2) *Effects on herbage of different frequencies and severities of cutting*

Various workers[2, 3] subscribe to the view that frequent cutting, severe cutting, and particularly a combination of both, will lead to decreased yields as compared with lenient cutting carried out at long intervals of time.

According to Stapledon[4], the continued plucking of inflorescences as they appear favours root and top development. Ellett[5] supports this view while his work indicates that the decrease in herbage yield due to harsh cutting treatments may be more than compensated for by the increased protein percentage of the herbage actually produced. Aldous[6] disagrees, claiming that the higher protein percentage does not compensate for the loss in total yield caused by cutting. In India, Lander[7] reports that in a dry season his experiments confirmed Ellett's findings, while in the following year, a wetter one, they confirmed Aldous' argument. It is possible that Aldous' results would apply under the conditions that prevail over the greater part of New Zealand.

(3) *Effect of stage of growth on the nutrient content of herbage*

Nutrient content varies with the stage of growth and the percentage of protein on a dry-weight basis is highest at periods of least growth[7]. Bukey[8] noted a marked decrease in the percentage carbohydrate content, on a dry-weight basis, under severe cutting conditions. The storage of carbohydrate reserves by grasses is cyclic in nature[9]. Minimum storage coincided with maximum top growth; maximum storage occurred in autumn at the completion of secondary herbage growth. Carbohydrate reserves that have been accumulated in roots and stem bases condition early spring growth, while the amount of the reserve itself is conditioned by the amount of foliage present during the normal storage period. Hence, severity of cutting is a major influence determining the quantity of carbohydrate reserves. Depletion of food reserves consequent on cutting implies limited root growth and a lowered capacity to resist adverse conditions.[10]

(4) *Stimulatory effect of cutting treatments on top growth*

Hodgson[11] holds that immediately following an initial cutting and/or infrequent close cuttings of established grass plants, a rapid regeneration of top growth may be recognised. With cocksfoot, he found that the rate of regeneration decreased following frequent subsequent cuttings.

(5) *Effect of defoliation on root growth*

Weinmann and others[12] state that there is a close relationship between roots and tops. All agree that frequent clipping of top growth results in poor root growth. Species react differently to different intensities of defoliation, and there are strain differences in cocksfoot.[13]

(6) *Seasonal growth of roots*

It is fairly definite that root growth is seasonal. At Rhode Island, Stuckey[14] found that root growth was at a minimum in late summer-autumn period, with a maximum in early spring, falling away again

through the summer. She classified plants into "annual" and "perennial" groupings according to rooting behaviour, perennial ryegrass being an "annual" and cocksfoot a "perennial." Martin[15] found roots had special growth periods and that removal of tops during these periods inhibited subsequent root growth.

(7) Effect of restriction of root growth on the growth of tops

Any inhibition of root growth will be reflected almost immediately in top growth. Robertson[16] records a decrease in tiller numbers and tiller size concurrent with restriction of root growth. Nedrow[2] after root-pruning grasses at a depth of 5 in. found decreases in top yields up to 50 per cent. Jacques[17] claims that from the point of view of increased herbage yields "no advantage is to be looked for as a result of root pruning in grasses".

(8) Influence of soil moisture on root growth

Soil moisture is one of the important factors which influence root growth. While soil moisture affect plants, so too can plants affect soil moisture content. Actively growing plants cause moisture gradients in the soil, making it impossible to obtain a truly representative sample for moisture testing[18]. Nedrow[2] suggests a figure of 34 per cent moisture content (dry-weight basis) as being about the optimum for his soil. The New Zealand Wheat Research Institute[19] suggests 20 per cent as being optimum for wheat, when the field capacity of the soil concerned is about 27 per cent, and found that few if any roots penetrate into a soil of 11 per cent moisture content[18].

EXPERIMENTAL METHODS

The experiment consisted of top-cutting and root-pruning carried out on three grasses: certified perennial ryegrass, uncertified perennial ryegrass, and cocksfoot.

The object was to investigate the influence of different cutting treatments on yield of tops as measured by their dry-weight, and on root-growth as measured by the number of new roots initiated, i.e. "crown roots". The effect of root-pruning on herbage growth was also investigated. It was further hoped to show by periodic soil-moisture determinations that initiation of new roots and soil moisture content could be correlated. Soil moisture variation, seasonal changes, the variations in top treatment and root pruning were each expected to produce measureable stimuli. The variations which occurred in the number of new roots initiated and the weight of herbage cut were taken as a measure of the response of the plant to the various stimuli set up.

Top treatments consisted of cutting the foliage to ½ in. to 1 in. and to 2 in. from ground level for two frequencies, viz. weekly and fortnightly, giving in effect 6 top treatments.

Root treatments consisted of: (a) a control where roots were not removed; and (b) the weekly removal of new roots. Thus, one series of 6 top treatments was root-pruned while the other series of 6 was not, giving 12 treatments in all. There were three grasses in the trial, giving 36 treatments for the experiment; each treatment occurred once at random in each of 15 replicated blocks.

The root-pruning treatment was simplified by mounting each plant on a dome-shaped knob of hydrated "plaster-of-paris" which was sunk into the soil to a depth which kept the crown of the plant at a normal

level. After a period of establishment, all plant bases were bared of soil to a depth of 1 in. Each excavation so formed was filled with easily removable sphagnum moss. (Fig. 1.) Opposed 3 in. x 4 in. notched wooden covers of $\frac{1}{4}$ in. pine wood were placed on the moss and around the plant to reduce loss of moisture, to allow easy access to the roots and to keep out birds.

FIG. 1.—Perennial Ryegrass plant in position in the soil showing—
(*a*) plaster of paris cone beneath the plant and three of the six roots growing over it;
(*b*) sphagnum moss in position beneath;
(*c*) wooden covers.

Removal of the light coloured new roots from the appropriate plants was greatly simplified by the collar of moss. In view of the variation likely to arise if seeds were used to produce plants for this experiment, it was considered that clones* would serve better. Plants were obtained through the courtesy of the Grasslands Division, Department of Scientific and Industrial Research, and were broken into sufficient clones to give one plant of cocksfoot, and one of each of the ryegrasses for all treatments. The plaster knobs were made in dome-shaped clay moulds (1½ in. deep and 1¼ in. diameter at the base). As the plaster set, 4-in. lengths of 8 gauge wire were inserted into the base to provide anchorage when the knob was imbedded in the soil. The experimental area, 1 ch long by ½ ch wide, was level and the soil fertile. Individual plants were 15 in. apart within the block with a double spacing of 30 in. between blocks. Planting was carried out on 24 and 25 March 1948. All plants were given two pretreatment herbage cuts at the experimental height (16 April and 7 May), with the first experimental cut taking place on 14 May. From 29 April to 7 May, the bases of all plants were bared, and all save six functioning roots were removed with scissors. The first experimental root treatment was carried out on 17 May, 1948, and the experiment was terminated on 15 February, 1949.

Soil moisture samples were taken from only a small area in the plot, which was kept free of herbage, so they were not truly representative of the moisture relationship around the plants. Soil moisture figures are included to indicate moisture trends, but conclusions have not been based thereon. Plants which died during the trial were allotted "expected" values in the data, by the use of Yates' "missing yield formula"[20], while a modification of it was used to calculate expected values for spilt samples. Two analyses of variance were carried out—one for the variance in top growth, and the other for variance in root initiation over the whole experimental period.

Top growth was removed with adapted sheep-shears which had metal strips welded to the non-cutting edges to retain all cut herbage. The clippings so obtained were then transferred to small metal pans of known weight. The pans and contents were then placed in an oven and dried under the standard conditions prescribed by Melville[21]. The drying had two phases, firstly, a preliminary drying to 70°C. for 4 hr in an electrically heated forced-draught oven to terminate transpiration, and secondly, a drying for 12 to 15 hr at 100 - 105°C. in an unventilated electric oven. Root counts were made by removing the wooden covers and moss from about the plant, and by pruning off all new roots (easily seen by their lighter colour) with a small pair of curved scissors. A count of the number removed from each plant was taken as pruning proceeded. The moss and covers were then replaced and left undisturbed for another week.

RESULTS AND DISCUSSION

Results for top growth are shown in Tables I and II, and for roots in Tables III and IV. Just as the different heights and frequencies of cutting influenced the yield of top growth, so too their effect was reflected in the number of roots that were initiated and pruned off at the base of the plants. Similarly, the effect of pruning off the new roots each week

* Wherever the term clone is used it refers to an individual plant derived asexually from one of the "species".

was reflected in the dry-weight of top growth removed. For these reasons, in the results the presence and absence of regular root-pruning are included in top treatments, while the varying heights and frequencies of cutting tops are included in the root treatments.

Top Growth

TABLE I.—TOP GROWTH: TREATMENT MEAN YIELDS

Height of cutting	Root treatment	Frequency of cutting	Perennial rye (certified) (g)	Perennial rye (uncertified) (g)	Cocksfoot (g)
½ in.	Pruned	Weekly	5.14	2.16	4.72
		Fortnightly	7.83	4.24	8.59
	Unpruned	Weekly	5.47	4.34	7.34
		Fortnightly	11.41	8.33	17.04
1 in.	Pruned	Weekly	6.77	3.33	5.72
		Fortnightly	9.65	6.10	9.89
	Unpruned	Weekly	9.20	7.57	11.85
		Fortnightly	19.04	13.14	30.22
2 in.	Pruned	Weekly	10.06	5.99	12.78
		Fortnightly	12.13	6.66	15.57
	Unpruned	Weekly	22.48	14.07	27.22
		Fortnightly	36.82	25.56	48.95
General Mean = 12.71					

TABLE II. ANALYSIS OF VARIANCE IN TOP GROWTH.

Source of variance	Degrees of Freedom	Mean square	Significance
Total	533	124.11	S
between Blocks	14	46.12	SS
„ Species (Sp)*	2	3050.86	SS
„ Frequencies (Fr)	1	6485.52	SS
„ Cuttings (Cu)	2	7546.58	SS
„ Prunings (Pr)	1	13876.98	SS
interaction between Sp x Fr	2	371.98	SS
„ „ Sp x Cu	4	283.28	SS
„ „ Sp x Pr	2	575.39	SS
„ „ Fr x Cu	2	199.64	SS
„ „ Fr x Pr	1	2484.63	SS
„ „ Cu x Pr	2	2698.58	SS
Second order interaction	12	111.09	SS
Error variance	488	23.16	

S = significant at the 5 per cent level of probability.
SS = significant at the 1 per cent level of probability.
Standard deviation = 4.81.
3rd order interaction failed to achieve significance and was bulked with error variance.

* Wherever the word "species" appears in this section the reference is to the three grasses used in the experiment.

From Tables I and II it is evident that:

(1) There was significant variation between blocks (as measured by dry-weight of tops). Within the blocks, the species contributed in regular manner to yield. Thus for any block, cocksfoot yielded most, and uncertified perennial ryegrass least, the differences between cocksfoot and certified perennial ryegrass, and between certified perennial ryegrass and uncertified perennial ryegrass were of much the same order in all blocks.

(2) There were significant differences in yields of dry top-growth between cocksfoot, certified perennial ryegrass, and uncertified perennial ryegrass for the experiment as a whole. The average cocksfoot clone yielded 16.674 g. of dry top-growth for the whole experimental period irrespective of the various treatments, whilst certified perennial ryegrass and uncertified perennial ryegrass yielded 13.000 g. and 8.456 g. respectively. (Fig. 2.)

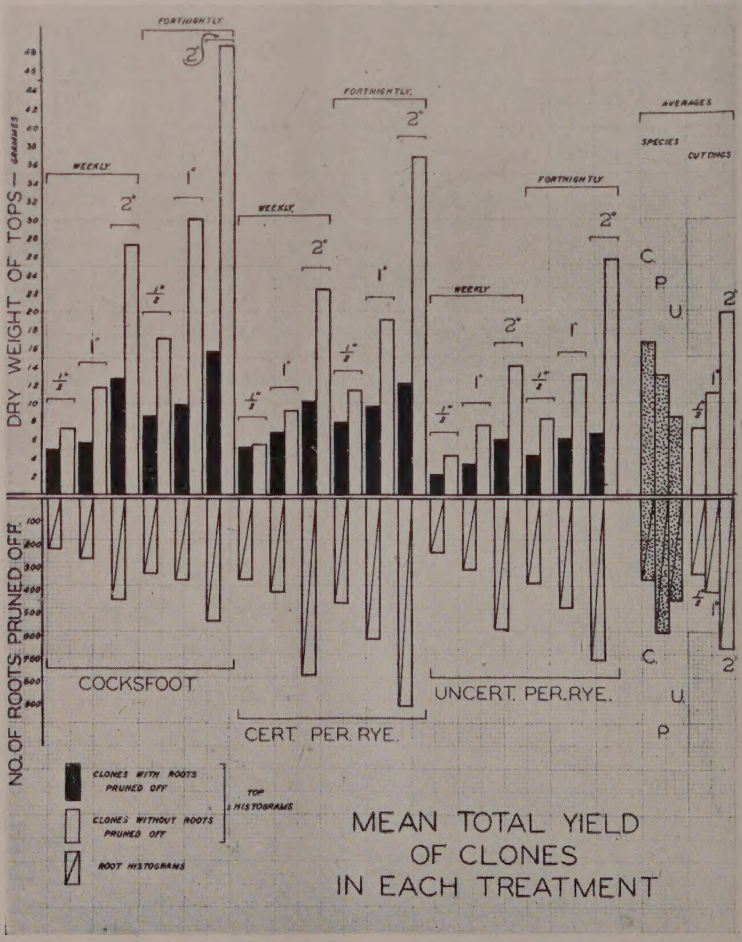

FIG. 2.—Root and top histograms of the three "species" under trial.

(3) Clones cut weekly yielded significantly less than did clones cut fortnightly. (Fig. 2.)

(4) The differences in yield between the three levels of cutting were significant, irrespective of species and treatment considerations, and were consistent within each species group and each treatment group. (Fig. 2.)

(5) Clones subjected to root-pruning gave significantly lower yields than clones not subjected to root-pruning. (Fig. 2.)

(6) From interpretation of the first order interactions, the differences in yield of the root-pruned clones, as opposed to those not root-pruned, were statistically significant in each of the three cutting treatments, in each of the frequency groups (weekly and fortnightly), as well as in each of the three species groups. The differences between the three heights of cutting were statistically significant in each of the three grasses. Likewise the difference was significant between weekly cuttings and fortnightly cuttings in each of the three grasses. Further, the dry matter yields for the three heights of cutting within the weekly-cut group were significantly lower than those in the fortnightly-cut group.

(7) The differences between species were significant for each of the three heights of cutting in turn, as well as being significant in the aggregate, as mentioned above.

(8) The difference between clones cut weekly and clones cut fortnightly was significant for each of the three heights of cutting.

(9) The difference between clones root-pruned and those not root-pruned was significant for each of the three grasses.

Other features of top growth were as follows:

(*a*) By elucidating the components of variance, it was found that the major factors, viz. removal of new roots effect, height of cutting effect, frequency of cutting effect and species effect, contributed 50 per cent of all variance, whilst error variance contributed 13.5 per cent. Of the major factors, root-pruning contributed 19 per cent of the variance, height of cutting 15 per cent, frequency of cutting 9 per cent, and species 7 per cent.

(*b*) Preliminary herbage cuts were made on 16 April and 7 May, but the clippings were not weighed. Weight figures obtained on 14 May suggest that a double stimulus was operating. (Fig. 3.) In the first case the clones that were cut to the ½-in. level outyielded those cut to the 1-in. level, and the latter in turn outyielded the clones cut to 2 in. This stimulus, while possibly operative between 16 April and 7 May cuts, was lost within two weeks of the last pretreatment cut. Thereafter, the most lenient cutting produced the highest yield. The second stimulus noted was in connection with root-pruning. It was expected that the root-pruned clones would be outyielded by those not root-pruned, and this did eventually occur. For the early period of the trial, however, the reverse occurred; clones subjected to weekly root-pruning varied in their response to it, according to the treatment suffered by the tops. The root-pruning stimulus lasted approximately 4½ weeks from the pretreatment cut for clones cut to a height of 2 in., 5½ weeks for clones cut to 1 in., and 7½ weeks for clones cut to the ½-in. level. Thereafter, in all cases clones yielded the greatest herbage weights when cut to 2 in. Those with unpruned roots outyielded those that were root-pruned.

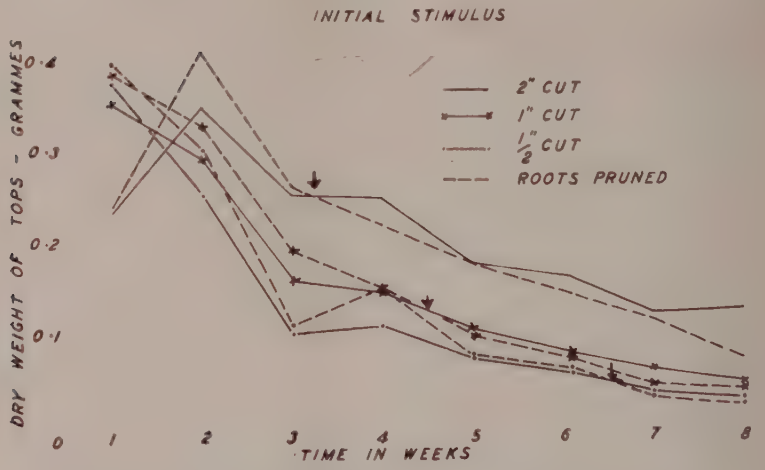

FIG. 3.—The double initial stimulus. (1) Initially the clones cut to the ½-in. level outyielded the others and the 1-in. cut outyielded the 2-in cut; this was reversed within two weeks of the last pretreatment cut. (2) Root-pruned clones outyielded those not root-pruned; this was reversed in 4⅓ weeks for the 2-in. cut, 5½ weeks for the 1-in. cut and 7½ weeks for the ½-in. cut clones.

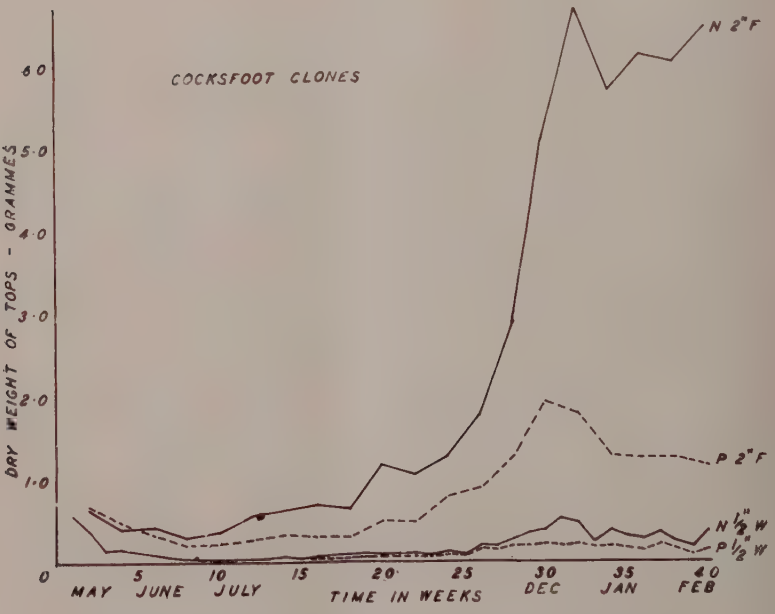

FIG. 4.—Yield over the experimental period of the cocksfoot clones subjected to the two most contrasting levels of cutting. Plants cut back weekly (W) or fortnightly (F), root-pruned (P) or non root-pruned (N).

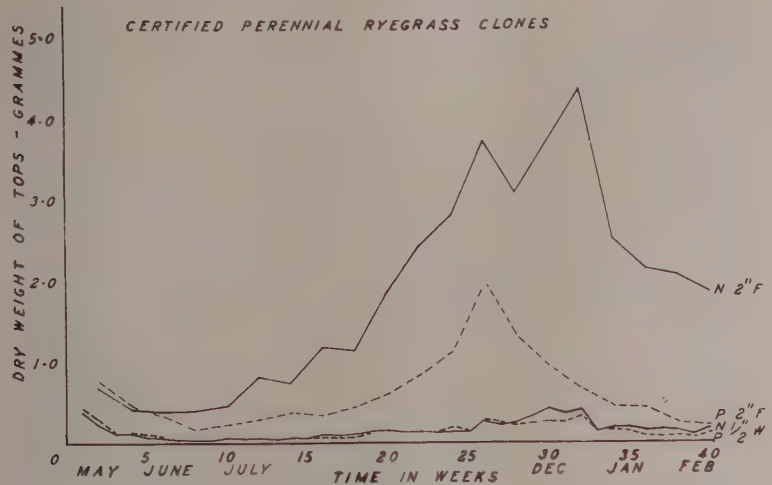

FIG. 5.—Yield over the experimental period of the certified perennial ryegrass clones subjected to the two most contrasting levels of cutting. Plants cut back weekly (W) or fortnightly (F), root-pruned (P) or non root-pruned (N.).

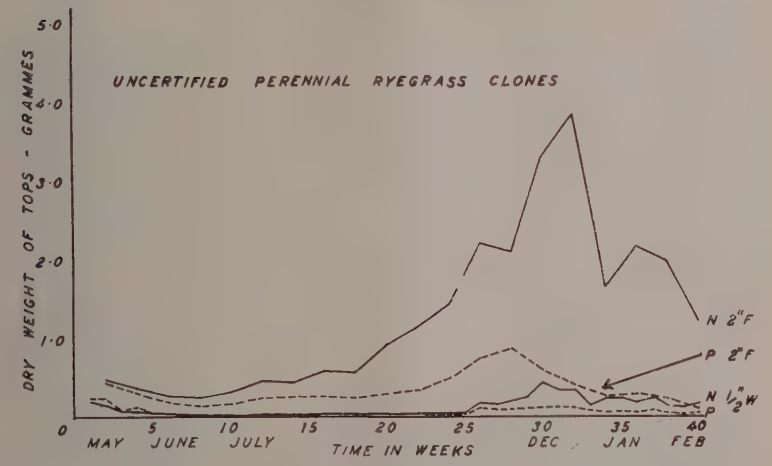

FIG. 6.—Yield over the experimental period of the uncertified perennial ryegrass clones subjected to the two most contrasting levels of cutting. Plants cut back weekly (W) or fortnightly (F), root-pruned (P) or non root-pruned (N).

(*c*) Throughout the experiment, species differences were obvious. Relative and seasonal yields were typical for each species though under pasture conditions perennial ryegrass outyields cocksfoot.

(*d*) The more lenient treatments responded to the onset of spring earlier than did the less lenient; certified perennial ryegrass, for example, in the 2-in. cut clones commenced vigorous growth from two to three weeks earlier than did ½-in. cut clones.

(*c*) In general, the 2-in. cutting treatments permitted clones to continue production further into the summer than did the less lenient treatments, and to reach their peak production after that of the less lenient treatments had passed.

Root Growth

Table III. Root Initiation: Treatment Mean Numbers

Height of cutting	Root treatment	Frequency of cutting	Perennial rye (certified)	Perennial rye (uncertified)	Cocksfoot
½ in.	Weekly pruning	Weekly	355	235	222
		Fortnightly	454	367	327
	Terminal pruning	Weekly	114	133	154
		Fortnightly	185	212	244
1 in.	Weekly pruning	Weekly	418	308	265
		Fortnightly	616	478	355
	Terminal pruning	Weekly	146	201	197
		Fortnightly	239	246	338
2 in.	Weekly pruning	Weekly	769	567	441
		Fortnightly	903	703	524
	Terminal pruning	Weekly	241	280	303
		Fortnightly	394	356	414

General Mean = 353. General Mean of weekly pruning = 461.

Table IV. Analysis of Variance in Root Numbers

Source of variance	Degrees of Freedom	Mean square	Significance
Total	265	49867.1	SS
between Blocks	14	82098.2	SS
„ Species (Sp)	2	1216274.2	SS
„ Frequencies (Fr.)	1	1095066.8	SS
„ Cuttings (Cu)	2	2571984.1	SS
interaction between Sp x Fr	2	20205.5	—
„ „ Sp x Cu	4	97798.0	SS
„ „ Fr x Cu	2	11014.1	—
Error variance	238	12353.8	

SS = significant at the 5 per cent level of probability.
Standard deviation = 111.15.
2nd order interaction failed to achieve significance and was balked with error variance.

From Tables III and IV it can be seen that:

(1) There was significant variation between blocks. As with the top yields, here again, with root numbers, species assumed a regular order in every block.

(2) The three species showed significant differences in their ability to initiate new roots. Certified perennial ryegrass initiated significantly more roots than did uncertified perennial ryegrass, while cocksfoot initiated significantly fewer roots than did uncertified perennial ryegrass.

(3) Clones subjected to weekly top-cutting initiated significantly fewer new roots than did clones subjected to fortnightly top-cutting treatments. (Fig. 7.)

(4) Clones cut at the ½-in. 1-in. and 2-in. levels differed significantly in root numbers for each level of cutting, irrespective of the other factors under test. (Fig. 7.)

(5) The three levels of top-cutting produced significantly different responses in each of the three grasses.

(6) The significant species differences recorded for the whole experiment in Tables III and IV were also significant within each of the frequencies of top-cutting.

(7) Root initiation by clones subjected to weekly top-cutting differed significantly from that of clones subjected to fortnightly top-cutting, taking the experiment as a whole. This difference was also significant within each species group, and also within each of three levels of top-cutting. (Fig. 7.)

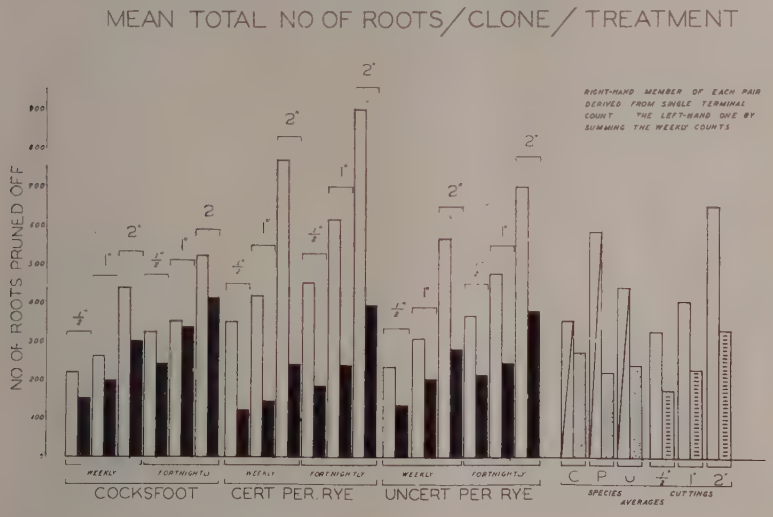

Fig. 7.—Mean total number of roots produced per clone for each "species" and treatment

Other features of root growth were as follows:

(*a*) From elucidation of the components of variance, it was found that the main factors, viz. height of top-cutting, species effect, and frequency of top-cutting, contributed 69 per cent of all variance. Of this, 40 per cent was due to height of top-cutting, 18 per cent was due to species differences, and 11 per cent to the frequency of top-cutting. The more lenient top treatments permitted a higher rate of root initiation, while the less lenient treatments gave a lower rate of initiation; thus, the 2-in. top-cuttings carried out fortnightly permitted greater root initiation than did any other treatment.

(*b*) Root initiation appeared to be seasonal. Initiation of new roots proceeded slowly from the start of the trial until mid-winter, then followed a period of great activity until late spring; this was followed by a decrease in the summer. Species differences in rate of root initiation at various times during the trial were marked (Fig. 8). The difference

in root numbers between the minimum initiation and maximum initation in cocksfoot was small, while certified perennial ryegrass showed most variation. Uncertified perennial ryegrass closely followed the trends of certified perennial ryegrass, although the rate of initiation was at a consistently lower level.

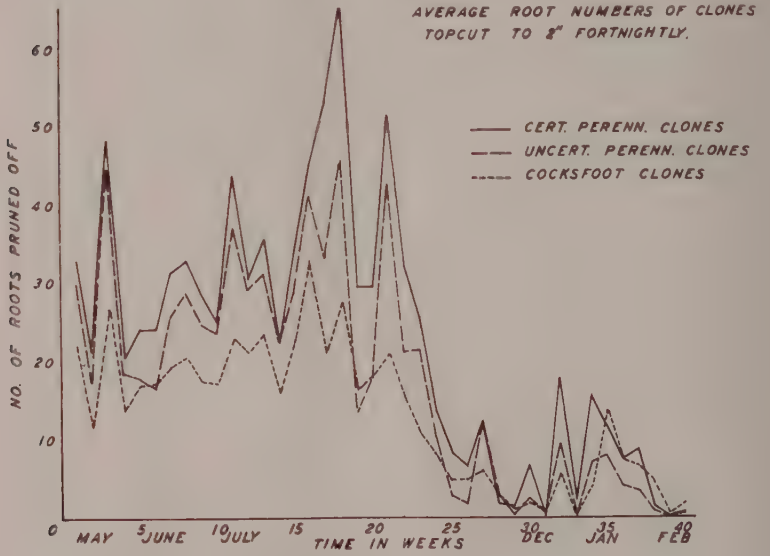

FIG. 8.—Average numbers of roots pruned off clones of the three species topcut to the 2-in. level fortnightly. (Other top treatments gave lower numbers throughout but they followed the trends here seen.)

(*c*) A terminal count of "crown roots" of clones that were not root-pruned during the trial showed similar trends to those ruling in clones subjected to regular root-pruning. Clones with tops cut to $\frac{1}{2}$ in. produced fewer roots than did clones top-cut to 1-in. height; those cut to 2-in. height produced the largest numbers. Clones subjected to a weekly cut had fewer roots than the clones under the fortnightly cut. Whereas under regular root-pruning, certified perennial ryegrass initiated the most roots and cocksfoot the least, in the terminal count where no root-pruning had taken place the order was reversed, i.e. cocksfoot possessed most roots, uncertified perennial ryegrass fewer and certified perennial ryegrass the least number of roots. The ratios between the total number of roots developed on the root-pruned plants and the total number that developed on the unpruned plants (as determined by the terminal count) are shown in Table V.

TABLE V. RATIO OF NUMBER OF ROOTS PRUNED OFF TO THE TOTAL NUMBER OF ROOTS FORMED ON THE UNPRUNED PLANTS

Species	Level of cutting		
	$\frac{1}{2}$ in.	1 in.	2 in.
Cocksfoot	1 : 0.72	1 : 0.86	1 : 0.74
Certified perennial ryegrass	1 : 0.37	1 : 0.38	1 : 0.38
Uncertified perennial ryegrass	1 : 0.57	1 : 0.57	1 : 0.50

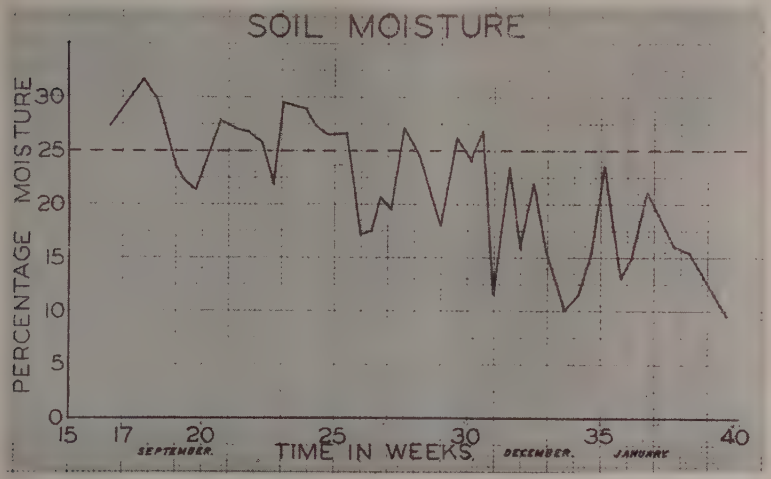

Fig. 9.—Soil moisture percentages from September to January. (Samples taken from an area without plants.)

Soil Moisture

(1) During the sampling period, soil moisture ranged from 32 to 9.5 per cent, there being a gradual reduction during the period 1 September to 16 February, 1949 (Fig. 9.)

(2) When soil moisture was greater than 25 per cent, initiation of new roots proceeded at a rapid rate.

(3) Root initiation almost ceased at the 10 - 12 per cent soil-moisture level.

Differential Growth

(1) Maximum root initiation occurred at a time when herbage growth was, in general, slow, viz. winter to mid-spring (July to early September).

(2) Maximum herbage growth occurred at a time when the rate of root initiation was, in general, low, viz. mid-spring to mid-summer (mid-September to end of December). The rate of root initiation increased in July. As it waned in mid-September, the rate of herbage growth rose. There was a very marked falling away in the rate of root initiation between mid-September and mid-October. From that time until the end of the trial, the rate of root initiation was low, while the rate of herbage growth was, in the main, high—at least where the more lenient treatments were operative.

Conclusions

The trial may be regarded as an evaluation of stimuli set up by root and top treatments accorded to plants grown under comparable soil and weather conditions. The basis of measurement of the root stimulus was the number of roots initiated, and that of the top stimulus was the dry weight of the herbage harvested at regular intervals. An effort has been made to isolate the effect of each stimulus, even though the interactions of two or more were operative at the same time.

(1) Cocksfoot plants produced the largest weight of herbage under all treatments of top-cutting, whether the roots were pruned or not. Certified perennial ryegrass was next, and uncertified perennial ryegrass produced the least. Even with the hardest top-cutting treatment superimposed on root pruning, the same order was maintained despite the fact that cocksfoot is generally considered to be adversely affected by close and frequent defoliation.

(2) As was to be expected, the herbage yield from fortnightly cuttings was significantly greater than that from weekly cuttings over the same period. Similarly, the expected increase in yield which accrues from a 2-in. cutting level as opposed to a ½-in. level was apparent in all species. The stimulus operative here is based on the maintenance of food reserves in both root and shoot, and also on the proportion of photosynthetic tissue that remains on the plant after each cutting treatment. It follows that where the major portion of photosynthetic issue has to be reformed after each cutting, there is a drain on food reserves, and a diminution in the quantity of food manufactured by the leaves. The growth rate as measured by production of dry matter from the tops is in proportion to the degree of defoliation, as well as to its frequency. These two stimuli operate in a parallel direction. When the more frequent (weekly) cutting was superimposed on the most severe cutting treatment (½-in.), the yield of dried herbage over all clones, irrespective of species, was only approximately one-fifth that of the most lenient traetment, i.e. fortnightly at 2-in. level.

(3) The yield of dry herbage was influenced by the weekly removal of the new roots.

(*a*) When the tops were cut weekly but not root-pruned, the yield was about double that of plants cut weekly but where all the roots (other than the original six) were pruned off. When cut fortnightly and not root-pruned, the yield was over 2½ times that where all new roots were pruned off. These differences in yield were consistent in all species for both weekly and fortnightly cuttings, but due to a large interaction between frequency and prunings, the differences did not achieve significance.

(*b*) The pruning of roots led to a decrease in herbage weights for all levels of cutting, but the greatest proportionate reduction was found in the 2-in. cutting level. (Figs. 4, 5, 6.) It would appear that where the hard cutting treatment (½-in.) was adopted, the six roots which were allowed each plant were unable to function to their fullest extent, due to the lack of photosynthetic tissue and the possible drain of food reserves to replace it as it was removed. With the more lenient cutting treatment (2-in.), there was always more green leaf tissue remaining on the plant after cutting, so that the six roots were able to function more effectively. The proportionate overall increase from the ½-in. cut plants that were not root-pruned over those that were, was small (60 per cent) as compared with that from the 2-in. cut plants (278 per cent).

(4) The numbers of roots that were produced and pruned off were greater in the fortnightly than in the weekly cuttings, and the cuttings at the 2-in. level gave greater numbers than at the 1-in. and ½-in. levels. In response to the stimulus of herbage removal, it would appear that severity of treatment, whether it be in time or in the height at which the tops are cut influenced the number of roots formed. The harder the pruning treatment, the greater was the tendency for formation of leaf

growth before that of roots. The prior demand by the plant was for photosynthetic tissue, and until such time as this was formed, an increase in the absorptive area of the roots was of secondary importance.

(5) An early stimulus, here called "initial stimulus", was apparent in both roots and tops.

(*a*) *Tops*: Before the commencement of the trial all clones had been cut to their correct heights, i.e. ½ in., 1 in. and 2 in. respectively. The first week's herbage weighings showed that those clones cut to the ½-in. level outyielded those cut to the 1-in level which in turn outyielded those cut to the 2-in. level. At the second cutting date (in the second week of the trial), the yields were reversed, and the lenient treatment gave the greatest yield, a condition which held good for the remainder of the experiment. It would appear that the first response of the plant following heavy defoliation was the rapid replacement of the photosynthetic tissue. If the defoliation is both frequent and severe the food reserves in the plant are insufficient to enable continued response to the stimulus, and the yield must fall into line with the reserves available. Had the plants been larger, and the reserves more extensive, it is possible that this stimulus would have been apparent for a longer period.

(*b*) *Roots*: An initial stimulus was also operative in the plants subjected to root-pruning. The root-pruned plants outyielded those that were not root-pruned for the first few weeks. For 4½ weeks from the pretreatment cut the 2-in. root-pruned clones outyielded the 2-in. non root-pruned clones; thereafter, the yield position was reversed. This changeover was reached in 5½ weeks with the 1-in. cut clones and in 7½ weeks for the ½-in. cut clones. It is apparent that the greater severity of cutting prolonged the effect of the stimulus. It would seem feasible to assume that the root-pruned plants received a sufficiency of nutrients from the six roots to produce more herbage than the non root-pruned plants which were developing both tops and roots at the same time. With the more lenient cutting treatments, an increase in root numbers in the unpruned clones enabled a greater yield of herbage to take place sooner than where the more severe cutting was practised, and where there were fewer new roots.

(6) The stimulus of root-pruning on root initiation was apparent from comparing counts made of roots removed by pruning with counts made at the termination of the experiment on non root-pruned clones. The root-pruned plants gave an average over all treatments and species of 461 roots per plant, while the average for the non root-pruned plants was 244. The greatest stimulus to root production was apparent where the top treatment had been most lenient, i.e. 2-in. cutting at fortnightly intervals. There was an interspecific difference in the response to this stimulus. Cocksfoot was comparatively unresponsive while certified perennial ryegrass was decidedly responsive, the uncertified perennial ryegrass being about midway between them. This points to a greater flexibility in the roots of ryegrass, which may account to some degree for its ability to withstand the diversity of treatments it is subjected to in farm practice.

(7) The periods of maximum production of roots and tops did not coincide. Root initiation was at its lowest in early June at a time when production of herbage was falling. Root numbers increased in June as the herbage continued to decline, and continued on the increase with

herbage-growth increase in the spring. Maximum root initiation was reached in October at a time when a decided increase in herbage production was becoming apparent. After October, root numbers fell away very rapidly until the lowest point was reached in December. There was a slight recovery in January, followed by an almost complete cessation in February. The herbage reached its peak of production from early November and into December, and thereafter fell away sharply, particularly in the ryegrasses. Thus, in October there was a marked changeover from root initiation to herbage production. In January, as herbage declined, there was a minor recovery in root initiation. These variations in root initiation and herbage production followed the same trend for all species, and were unaltered by cutting or root-pruning. As root and shoot behaviour was comparable for all treatments, it would appear that the alternation between root and top growth was not in response to any stimulus developed in this experiment, but rather, was a response to stimuli affecting normal physiological development.

(8) The rate of root initiation appears to be, to some extent at least, independent of the level of soil moisture, provided that it is above the minimum needed for initiation. There was over 25 per cent moisture present in the soil for most of the time until early November, and yet during this time the root numbers declined. The percentage moisture in the soil was considerably higher at this stage than in January when there was a renewal of root growth. There were insufficient data on soil moisture to warrant any conclusions being drawn on this aspect.

Acknowledgments

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ROOT DEVELOPMENT IN SOME COMMON NEW ZEALAND PASTURE PLANTS

VI. IMPORTANCE OF VARIOUS ROOTS, PARTICULARLY THE SEMINAL ROOTS OF PERENNIAL RYEGRASS (*Lolium perenne*)

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(*Received for publication, 9 November 1951*)

Summary

The relative importance of the primary and lateral seminal roots and nodal roots was compared by means of amputation trials.

The lateral seminal roots do not make any marked contribution to the food supply. The primary seminal root will keep the spring sown seedling alive for 3½ months from the time of sowing the seed. The nodal root system takes over the function of absorption from the seminal root system, but the latter has a measurable effect on tiller and leaf production for fully 5 months (the duration of the trial) over and above that of the nodal roots.

Fertilizer (superphosphate) application increased neither the length of life of plants dependent solely on the seminal root system, nor the number of tillers, but it did result in a highly significant increase in herbage yields irrespective of the root amputation treatment.

Introduction

It is known that with grasses the seminal roots, which are the first roots to develop, normally support the seedling plant until such time as the nodal root system becomes functional. When the store of food in the seed is exhausted the young seedling for a time is entirely dependent on the seminal root system.

To appreciate fully the significance of the part played by the seminal roots, one must recognize that during development prior to emergence, the size of the plant increases about four times[1]. As regards post-emergence development, Weaver and Zink[2] present data which indicate the tremendous development of the seminal roots for the first three months of growth, by which time the nodal root system is extensive and functional.

The seminal roots are often designated as temporary in general text-books[3],[4],[5]. Locke and Clarke[6], however, observed that in certain circumstances the seminal roots furnished sufficient moisture to maintain growth of wheat plants to maturity, or until the nodal roots were able to develop and function. The experiments of Krassovsky[7], Simmonds and Sallans[8], and Simmonds[9] show that the seminal roots of wheat can be functional throughout the life of the plants. Pavlychenko[1] also gives conclusive evidence that, in annual grasses in arid climates, seminal roots function throughout the entire growing season and, what is more important, they are frequently the only roots supporting the plant from emergence to maturity. Weaver and Zink[2] observed that the seminal roots of fourteen perennial grasses remained alive and active as absorbing organs for 3½ to 4 months, whereas Stoddart[10] found that, with *Andropogon furcatus*, such roots all lived to an age of 18 months, and that some were still functioning at the end of two years.

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Weaver[11], McCall[12], Olmsted[13] and Glendinning[14] observed that tillering in grasses is closely related to the development of the seminal and nodal root systems.

Sallans[16] found that the various roots of wheat contribute independently of each other to the water and mineral supply of the plant. His data illustrate that, of the seminal roots, the primary seminal root contributes most to the final yield. The first pair of lateral seminal roots is of approximately equal importance with the primary seminal root, whilst the second pair of lateral seminal roots is much less important. The contribution of the nodal roots is more variable.

Trials were laid down in the summer of 1949-50 at Massey Agricultural College to determine and separate the functions and value of the various roots to perennial ryegrass under New Zealand conditions.

EXPERIMENTAL METHODS

The experiment consisted of the following seven root amputation treatments in the presence and absence of superphosphate at the rate of 5 cwt per acre.

Root Treatments	*Treatment Designation*
Control (no roots amputated)	C
Primary seminal root amputated	P
Lateral seminal roots amputated	L
Nodal roots amputated	N
Primary and lateral seminal roots amputated	PL
Nodal and lateral seminal roots amputated	NL
Nodal and primary seminal roots amputated	NP

The treatments were allotted at random to a split-block designed layout of 32 replications, the fertilized plants being confined to one half of a whole block and the non-fertilized plants to the other half. There were 28 plants in each block.

Prior to the sowing of the seed the top inch of surface soil was removed and the equivalent of 5 cwt of superphosphate per acre was mixed with a core of soil 6 in. in diameter and 3 in. in depth in the plant positions that were to receive the fertilizer treatment (Fig. 1). The surface soil was then replaced.

The perennial ryegrass seed, A 1695, obtained from the Grasslands Division, Department of Scientific and Industrial Research, was sown on 19 October, 1949 at a depth of $\frac{3}{4}$ in. so that the two root systems would be separated by a long internode and readily distinguished.

Flat rubber discs of $1\frac{1}{2}$ in. diameter and $\frac{1}{8}$ in. thick, with a central hole of $\frac{1}{16}$ in. diameter were placed around the internode immediately above the seed on all plants on 8-10 November, 1949. The plants had reached the two leaf stage. The soil at the base of each plant was excavated so that the seed was exposed. The leaves were inserted into the central hole in the rubber disc, the rubber disc then slipped down the plant until it was lying just above the seed, and the soil replaced. In this way the wiry internode between the seed and the base of the plant was positioned through this central hole (see Fig. 1), and the two root systems effectively separated; the nodal system developed above, and the seminal system below the rubber disc.

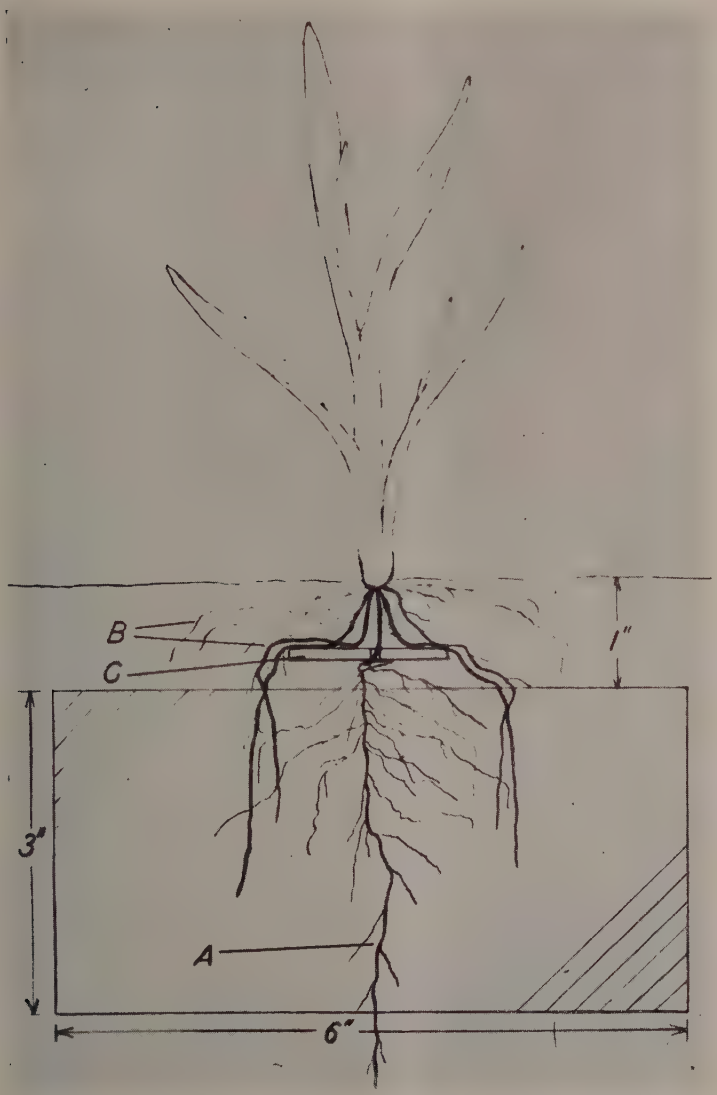

FIG. 1.—The placement of fertilizer and position of the rubber discs in relation to the various roots. The fertilized soil zone is partially shaded.

A. Primary seminal root.
B. Nodal roots.
C. Rubber disc.

The amputation of the nodal roots commenced on 15 November, 1949, and thereafter was carried out at approximately ten-day intervals. When the nodal roots were to be amputated the soil was removed from around the base of the plant to expose the rubber disc. It is to be noted that the rubber disc kept the soil at the base of the plant somewhat dry, making for easier removal of the soil. Whether or not this had any effect on root initiation was not determined. When the soil had been removed, the wiry internode was identified and all nodal roots were cut back hard against the base of the plant with a small pair of scissors. The soil was then replaced.

The amputation of the various seminal roots was effected on 22 and 23 November, 1949. The soil was excavated to expose the upper portions of the seminal roots and the seed so that the various seminal roots could be identified and amputated near the seed. Only one amputation was necessary, since the seminal roots cannot regenerate themselves. The soil was then replaced and the plants were ready for observations to be taken on the effect of these various root treatments.

At intervals, the number of tillers was counted for each plant in all treatments. The herbage was cut with modified sheep shears, as adapted by Marryatt and Simpson[17], to a height of 1 in. above ground level on 27-28 January and 11 March, 1950, dried and weighed. The four surviving root treatments were measured at both yield determinations.

Results

A. Effect of Treatments on Survival

Plants whose nodal and primary seminal roots were amputated did not survive and had all died within a few days of amputation of the roots. The lateral seminal roots, which were left intact were unable to supply sufficient water and nutrients to the plants to ensure the continuation of life. Consequently it is concluded that, in the case of perennial ryegrass, the lateral seminal roots alone cannot ensure continued survival.

Two other root treatments in which there was (1) amputation of nodal roots with seminal roots left intact, and (2) amputation of nodal and lateral seminal roots with primary seminal root left intact, both resulted in the less immediate death of the plant. Plants undergoing these two treatments gradually died during the period of the experiment, surviving up to 112 days, the average length of life from the time of sowing being almost three months. Plants of the remaining four treatments were still alive at the termination of the experiment, i.e. after 147 days.

The fertilizer application had no significant effect on the length of the life of the plants.

B. Effect of Treatments on Tillering

All four tiller counts showed that the fertilizer treatment was not significantly different from the non-fertilizer treatment at the various stages of plant development. There was, however, a tendency for the fertilized plants to have increased tiller numbers. Consequently, when comparing the effect of the various root treatments on tillering, all plants undergoing the same root treatments were combined irrespective of the fertilizer treatment.

The mean average tiller numbers for each root treatment at the various tiller counting dates are shown in Fig. 2. From these it will be noted that, when compared with the control treatment, the removal of the nodal roots markedly reduced tiller numbers, particularly at the later observations. The removal of the primary seminal root had a more or less intermediate effect between the control and nodal amputation treatments whereas lateral seminal roots amputation differed little from the control.

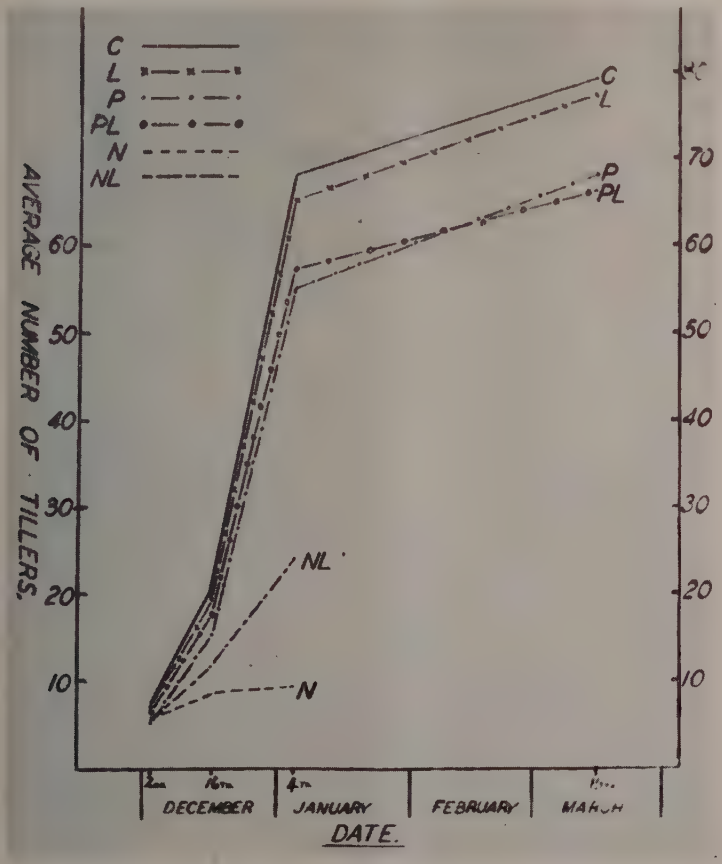

FIG. 2.—Graph of the mean average tiller numbers for the various root treatments at the four tiller counting dates.

By the use of the mean number of tillers at each tiller counting date for each root treatment, the mean differences between pairs of treatments were obtained; these were statistically examined by the "t" test, the results of which are given in Table I.

TABLE I. SIGNIFICANCE OF DIFFERENCE BETWEEN MEANS OF THE VARIOUS ROOT TREATMENTS COMPARED IN PAIRS AT THE VARIOUS DATES OF TILLER COUNTING

Treatment Comparisons	Date of Tiller Counting			
	2/12/49	16/12/49	4/1/50	15/3/50
C and N	SS	SS	SS	*
C and P	SS	SS	SS	S
C and L	—	—	—	—
C and NL	SS	SS	SS	*
C and PL	SS	SS	SS	SS
N and P	—	SS	SS	*
N and L	SS	SS	SS	*
N and NL	—	S	SS	—
N and PL	—	SS	SS	*
P and L	SS	SS	S	—
P and NL	—	SS	SS	*
P and PL	SS	—	—	—
L and NL	SS	SS	SS	*
L and PL	—	—	S	S
NL and PL	S	SS	SS	*

* Because of the non-survival of treatments N and NL the difference between means is assumed to be highly significant.

C. *Effect of Treatments on Herbage Yield*

(*1*) *Fertilizer Treatments:* The effect of the fertilizer treatments on mean average yield of herbage for each root treatment is presented in Fig. 3. From this it is seen that the application of 5 cwt of superphosphate results in a general overall increase in yield, and an analysis of variance proves the mean difference between fertilizer treatments to be significant. The increase in yield due to fertilizer is quite marked with all root treatments except the primary and lateral seminal roots amputation treatment, but because of a non-significant root-treatments/fertilizer-treatments interaction this deviation is not significant.

(*2*) *Root Treatments:* From Fig. 3 it will be observed that the amputation of the primary seminal root resulted in depressed yields of herbage whilst the amputation of the lateral seminal roots caused no depression of yields.

Statistical evaluation of herbage yield data indicates that primary seminal root amputation is significantly different from non-amputation of the primary seminal root, and that lateral seminal roots amputation is not significantly different from non-amputation of the lateral seminal roots. Table II summarizes the significance of the treatment comparisons.

TABLE II. SIGNIFICANCE OF DIFFERENCES IN EFFECT ON AVERAGE YIELDS BETWEEN THE VARIOUS ROOT TREATMENTS

Treatment Comparisons	Significance to 5% level
C and P	Significant
C and PL	Significant
C and L	Non-significant
P and PL	Non-significant
P and L	Significant
PL and L	Significant

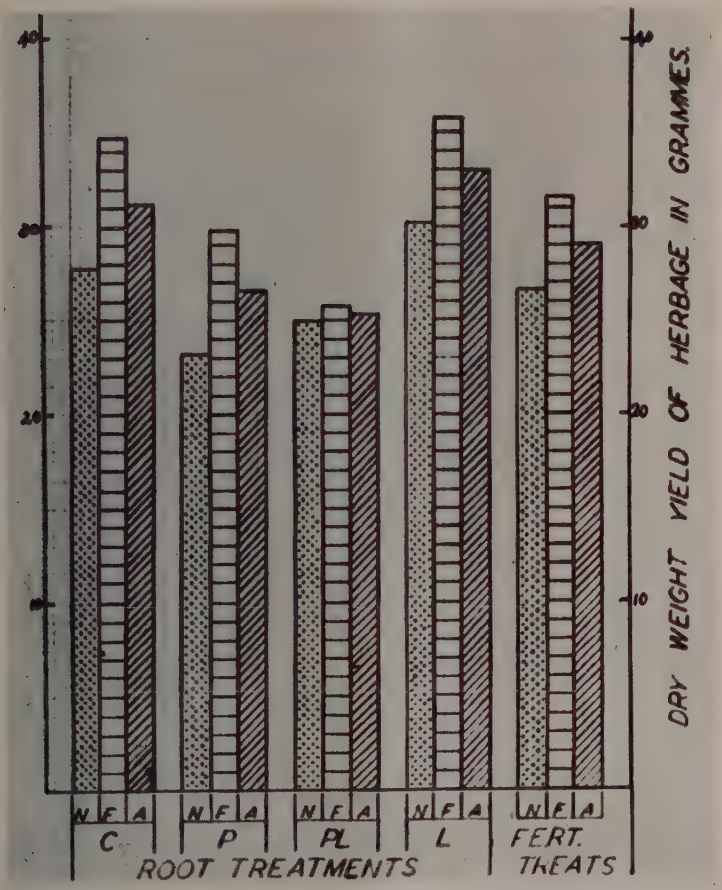

FIG. 3.—Histogram of the mean average dry weight herbage yields in grammes for the various treatments.
N = Non-fertilized.
F = Fertilized.
A = Average of N and F for the root treatment or the fertilizer treatment as indicated.

Because of the non-survival in the case of the three treatments: nodal roots amputated, nodal and lateral seminal roots amputated, and nodal and primary seminal roots amputated, it is considered justifiable to say that these three treatments are significantly different from the other four treatments. However, due to lack of sufficient data the significance of differences between these three treatments cannot be made.

The conclusions are that the amputation of the lateral seminal roots does not significantly reduce yield, the amputation of the primary seminal root reduces the yield significantly, whilst the amputation of the nodal roots results in a still greater and significant reduction in yield, ending in the death of the plants so treated.

Discussion

As a result of amputation experiments it is possible to determine the role of the seminal and nodal root systems in perennial ryegrass. Their reaction to the application of superphosphate is straightforward. The added fertilizer did not increase the length of life of the plants which had the nodal roots amputated, nor did it appear to enable the lateral seminal roots to alone support the plants. Plants in all the treatments which retained the nodal roots remained alive throughout the trial, so that no indication is given as to the effect of the fertilizer on their longevity.

The added fertilizer did not significantly increase the number of tillers per plant in any of the root amputation treatments, but it did result in a highly significant increase in herbage yields irrespective of the root treatments. The phosphate stimulation was thus operative for leaf growth but not for the development of shoot primordia. The non-significance of the root-treatments/fertilizer-treatments interaction for tiller numbers and herbage yield indicates that the effect of the superphosphate was independent of the root treatments.

The various root treatments had varying effects on survival, tillering and herbage yields. The levels of significance of the mean differences between root treatments was not always the same and in the case of tillering, it altered from one tiller counting date to the next.

The amputation of the lateral seminal roots had a non-significant effect on the length of life of the ryegrass plants. The removal of the lateral seminal roots made no difference to tillering and herbage yield, and plants were unable to survive when all roots other than the lateral roots were amputated. These facts may not hold good under conditions of amputation where a greater development of the lateral seminal roots is permitted, but in ryegrass it would appear that they contribute little to the plant's development at any stage.

The primary seminal root on the other hand is a more effective organ. Though its amputation did not bring about the death of the plants during the 5 months of the trial, it is clear that during the early stages of seedling growth it plays an important part in the supply of food. Its removal reduced the number of tillers as compared with the control, but not to the same extent as followed the removal of the nodal roots. Yield also was reduced even when the nodal roots were not removed, but the importance of this root declined as the nodal roots became more numerous. It would be logical to assume that the stage of growth attained by the seedling plant at the time of amputation of the primary seminal root is important. If amputated early, before the nodal roots have commenced to absorb, the plant would have difficulty in surviving the operation, particularly in view of the relatively low absorptive power of the lateral seminal roots. If amputated later, when the nodal root system is functioning, the effect would be on a decreasing scale in proportion to the stage of development of the nodal roots. The loss of the primary seminal root in these trials was still measurable in its effect on tiller and herbage production 5 months after being excised.

The nodal roots, when once they become functional, exert the strongest influence on growth. Where they were removed at regular short intervals, the seedling plants were able to survive only for a period up to $3\frac{1}{2}$ months from sowing the seed. Their removal significantly reduced tillering capacity and yield of herbage.

The nodal roots commence to develop at an early stage and their numbers increase in proportion to the number of tillers that develop. Any treatment that interferes with the initiation of tiller primordia must also have a like effect on root numbers and consequently on the rate of growth of the plant.

It would appear from this trial that the lateral seminal roots exert little effect on either establishment or subsequent growth of perennial ryegrass. The primary seminal root carries the plant over the period between the cessation of support from the endosperm and the effective operation of the nodal root system. The primary seminal root alone is capable of supporting the seedling plant for up to $3\frac{1}{2}$ months, but will not permit of any great extension in size during that period. The nodal roots become increasingly important as they replace the seminal root system.

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SPRAY TREATMENTS FOR CONTROL OF WOOLLY-APHIS (*Eriosoma Lanigerum* (Haus.)) ON APPLE TREES

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Summary

Results of spray experiments for control of woolly-aphis (*Eriosoma lanigerum*) show that BHC gave a high degree of control when used as dormant and as summer sprays. Tainting of the harvested crop was found to occur when technical BHC was applied in the growing season, but did not follow the use of dormant sprays. Where sprays were prepared with refined BHC containing 99 per cent gamma isomer, tainting of fruit did not occur even when the spray was applied three weeks from harvest.

DDT sprays applied in the growing season were found to kill large numbers of the parasite *Aphelinus mali* but did not affect woolly-aphis. As a result, increased populations of woolly-aphis occurred. BHC was also found to cause mortality of *A. mali*.

DDD failed to control woolly-aphis but caused almost complete eradication of *A. mali* and, in consequence, infestation of woolly-aphis developed to an extent greater than that which followed the use of DDT.

Dormant sprays of DNC-oil emulsion failed to control woolly-aphis. Dormant and summer sprays of parathion gave partial control of woolly-aphis but at comparable dosage rates were not as effective as BHC. The addition of winter petroleum oils to BHC and parathion sprays gave only a small improvement in control.

Introduction

The control of woolly-aphis (*Eriosoma lanigerum*) on apple trees has always been a difficult problem to the New Zealand orchardist, particularly on varieties such as Cox's Orange Pippin, Dunn's Favourite, Jonathan, etc., which are highly susceptible to attack. It is doubtful whether such varieties could have been grown commercially had it not been for the introduction and establishment of the parasite *Aphelinus mali* Hald. This parasite has had spectacular success, but like most host-parasite relationships the balance in nature fluctuates. Thus, it is not uncommon for a severe outbreak of woolly-aphis to develop early in the season before the population of *A. mali* can build up sufficiently to bring the infestation under control. By the end of the season parasitization is usually almost complete, but before this is achieved considerable damage may have been done. Typical effects of woolly-aphis attack are: (1) the development of "blind" buds, with consequent loss in fruiting spurs for future years; (2) restriction in growth, an effect which is particularly serious in young trees; and (3) blemishing of fruit, which reduces market value of crop.

With the introduction of DDT into orchard practice, growers have claimed that woolly-aphis infestations have tended to increase. Severe attacks have occurred in orchards where several applications of DDT have been used, but it has also been observed that in orchards where no DDT has been employed infestations have also shown marked increase in the same season and district.

The need for a spray treatment to control woolly-aphis in a season of severe infestation has been recognised for a long time. Recommended treatments of nicotine sulphate and nicotine sulphate plus summer oil have been used, but only with mediocre success. Where sprays can be

so directed that the protective woolly covering is penetrated, the aphids are readily killed, but in practice this is difficult to achieve, even with the aid of wetting agents. In the present paper, results of spray trials with several different insecticides are reported with special reference to the use of BHC (benzene hexachloride). Observations are also reported on the effects of DDT, and of the DDT analogue DDD (dichloro diphenyl dichloroethane) on populations of woolly-aphis and the parasite *A. mali*.

EXPERIMENTAL PROCEDURE

All experiments were carried out in the Nelson Province on varieties Dunn's Favourite, Cox's Orange Pippin, Jonathan and Sturmer. Sprays were applied from a high-pressure pump using six-foot lances with twin nozzles delivering approximately three gallons per minute at 300lb. pressure.

In addition to experimental sprays, all trees (except checks) received normal spray applications of sulphur and lead arsenate except that the latter was omitted from the mixture when applying the test insecticides.

Materials used

BHC (benzene hexachloride): For most of the experiments a wettable powder was used containing 50 per cent of the mixed isomers of BHC (technical grade) of which 12.5 per cent was gamma isomer. Dosage rates are given in terms of gamma BHC. In a few trials (noted in the text), a wettable powder was used which was prepared from BHC containing 98 per cent gamma isomer.

DDT (dichloro-diethyl-trichloroethane): In all trials, wettable powders were employed and dosage rates are given in terms of para para isomer of DDT.

DDD (dichloro-diethyl-dichloroethane): A wettable powder was used and dosage rates are given in terms of technical DDD.

DNC (dinitro-ortho-cresol): The DNC winter wash employed conformed to the specification laid down in Technical Bulletin No. 1 of the Ministry of Agriculture and Fisheries, United Kingdom, viz. a petroleum oil emulsion containing approximately 1.5 per cent DNC.

Winter oil: A miscible petroleum-oil emulsion was used of viscosity 150 (Redwoods I at 100°F.) and unsulphonated residue approximately 70 per cent. Dosage rates are given in terms of petroleum oil.

Summer oil: A petroleum oil emulsion was used of viscosity 80 (Redwoods I at 100°F.) and unsulphonated residue of 95 per cent. Dosage rates are given in terms of petroleum oil.

Parathion (Diethyl p-nitrophenyl thiophosphate): Wettable powders containing 15 per cent parathion were employed except in one trial in which a solvent emulsion containing 20 per cent parathion was used.

Attempts to measure results by counting aphis populations were found to be too tedious and time consuming for field work even on small samples. The following method was therefore adopted as a means of showing relative differences in infestation. Branches were selected at random in four different locations on each tree, and ten shoots of the current season's growth were examined in succession up each branch from shoulder height. Each shoot was recorded as clean or

infested and results are reported as the percentage of infested shoots. Analysis of variance has been carried out directly on figures for percentage infestation or, where these varied widely, on their equivalent angles.

RESULTS

1945-46 Season

Results given in Table I, show that four post-blossom applications of BHC on the variety Dunn's Favourite virtually eliminated woolly-aphis. As compared with normal spray and check treatments the use of DDT at both ½ and 2 lb per 100 gal showed significant increase in infestation, the increase being greatest at the lower dosage rates. A highly objectionable musty flavour was apparent in the harvested fruit from BHC Treatments 3 and 4.

TABLE I: [illegible] BHC ON VARIETY DUNN'S [illegible] WOOLLY-APHIS; SEASON 1945/46

Treatment No.	Concentration of Spray in 100 gal. water	Percentage shoots infested 9 April	Equivalent angle
1	DDT ½-lb.	55.0	47.8
2	DDT 2-lb.	5.8	19.3
3	Gamma BHC 1-oz.	1.2	6.5
4	Gamma BHC 2-oz.	0	0
5	Normal sprays	11.3	18.6
6	Check - no spray	11.9	20.1
	Difference for significance at 5%		10.5

(Sprays applied on 8 and 29 Nov., 19 Dec., and 16 Jan.; the first application in Treatment 4 was of 4-oz. gamma BHC, being reduced to 2-oz. for later sprays.)

1946-47 Season

Treatments were again carried out on trees of the variety Dunn's Favourite and were designed to show the effect on woolly-aphis control of combining DDT with BHC. Results given in Table II again show high degree of control by BHC and indicate that the combination of DDT with BHC did not materially affect the efficiency of the latter.

TABLE II: SUMMER APPLICATIONS OF DDT AND BHC ON VARIETY DUNN'S FAVOURITE FOR CONTROL OF WOOLLY-APHIS; SEASON 1946/47

*Treatment No.	Concentration of Spray in 100 gal. water	Percentage shoots infested 5 March	Infestation observed 5 March	
			Woolly-aphis	A. mali
1	DDT ½-lb.	53.2	heavy	slight
2	DDT ½-lb. plus gamma BHC 2-oz.	2.5	slight	slight
3	Gamma BHC 2-oz.	0	slight	slight
4	Normal spray	64.4	heavy	heavy

* (Sprays applied on 11 Nov., 3 and 20 Dec., 10 Jan.)

Infestation by woolly-aphis on trees receiving normal sprays was higher than in the previous season, indicating that parasitization by *A. mali* had not been as efficient. Where DDT was used alone, woolly-aphis infestation was lower than with the normal spray treatment, a result which was the opposite of that in the previous season.

Observations taken on 5 March showed that parasitization was proceeding vigorously on trees receiving normal spray treatments, whereas only a few parasitized aphids could be found on DDT and BHC treated trees. At this time the aphis population was developing rapidly where DDT was used alone.

An objectionable flavour was again apparent in the fruit harvested from trees which had received BHC.

1947-48 Season

Results of the trials described above showed that the value of BHC in commercial practice would be limited by the development of objectionable flavours in the harvested crop where several applications were made during the growing season. An experiment was designed therefore to show whether BHC applied once or twice in the period immediately following petal fall would give sufficient control of woolly-aphis without causing objectionable flavours in the harvested fruit. Trees of the variety Cox's Orange Pippin were sprayed, results being shown in Table III. Where a single application of BHC was made about 14 days after petal fall, a considerable reduction of woolly-aphis attack was secured, with a further reduction where a second application was made 18 days later.

DDT was applied in one treatment in this experiment and caused a significant increase in woolly-aphis attack as compared with the normal spray treatment. Observations taken on 20 February showed that parasitization by *A. mali* was proceeding vigorously on the trees receiving normal sprays but was much reduced on the BHC and DDT treatments.

Slight but distinct tainting was detected in fruit from trees which received one spray of BHC and more pronounced tainting when two sprays were applied.

TABLE III. SUMMER APPLICATIONS OF DDT AND BHC ON VARIETY COX'S ORANGE PIPPIN FOR CONTROL OF WOOLLY-APHIS: SEASON 1947/48

Treatment No.	Concentration of Spray in 100 gal. water	Shoots infested 27 Feb.		Infestation observed 20 Feb.	
		Percentage	Equivalent angle	Woolly-aphis	A. mali
1	DDT ¼-lb.	86.9	69.9	heavy	slight
2	Gamma BHC ½-lb.	39.4	38.7	slight to moderate	moderate
3	Gamma BHC ¼-lb.	17.5	23.9	slight	slight
4	Normal sprays	65.3	54.5	moderate to heavy	heavy
	Difference for significance at 5%			10.0	

* (In Treatments 1 to 3, sprays were applied on 7 Nov., with a second application of Treatment 3 on 25 Nov.)

1948-49 Season

Trees of the Sturmer variety were sprayed with DDT and DDD and compared with normal spray treatments and check. Although the experiment was concerned mainly with codling-moth and leaf-roller, some interesting results were obtained on woolly-aphis control and these are reported in Table IV.

Infestation was light on all treatments except where DDD was used and here a marked increase in woolly-aphis attack developed. Parasitization by *A. mali* was moderate on the normal spray treatment and check, much reduced where DDT was used and practically absent on the DDD treatment.

TABLE IV. SUMMER APPLICATIONS OF DDT AND DDD ON VARIETY STURMER FOR CONTROL OF WOOLLY-APHIS: SEASON 1948/49

*Treatment No.	Concentration of Spray in 100 gal. water	Shoots infested 9 May		Infestation observed 24 April	
		Percentage	Equivalent angle	Woolly-aphis	A. mali
1	DDT ¼-lb.	20.6	26.8	moderate	slight
2	DDD ¼-lb.	66.5	55.0	moderate to heavy	absent to slight
3	Normal sprays	15.0	22.2	slight	moderate
4	Check - no spray	18.8	25.0	slight	moderate
	Difference for significance at 5%			14.1	

* (In Treatments 1 and 2, sprays applied 19 Nov., 9 and 29 Dec., 18 Jan. and 10 Feb.)

1948-49 Season

In view of the fact that BHC appeared likely to cause tainting even where only one spray was applied early in the growing season, it was decided to test the efficacy of dormant applications. In the same trial DNC-oil emulsion and DDT treatments were included. Dosage rates higher than would normally be considered economic were employed in order to ascertain whether dormant treatments were likely to be worthy of further investigation. Treatments were carried out on the variety Dunn's Favourite and results are given in Table V.

TABLE V. DORMANT APPLICATIONS OF DNC, DDT AND BHC ON VARIETY DUNN'S FAVOURITE FOR CONTROL OF WOOLLY-APHIS: SEASON 1948/49

*Treatment No.	Concentration of Spray in 100 gal. water	Percentage shoots infested 14 March	Infestation observed 10 Feb.	
			Woolly-aphis	A. mali
1	DNC-oil emulsion 9-gal.	94.5	moderate to heavy	moderate
2	DDT 10-lb.	65.8	moderate	slight
3	Gamma BHC 10-oz.	21.8	slight	slight
4	Gamma BHC 10-oz.	18.6	slight	slight
5	Check - no spray	95.0	moderate to heavy	moderate

* (In Treatments 1 to 4, sprays applied 31 Aug; in Treatment 3 a wettable powder was used and in Treatment 4, a solvent emulsion.)

Woolly-aphis infestations were considerably reduced by both formulations of BHC. Both DDT and DNC-oil emulsion proved ineffective. Observations taken on 10 February showed a moderate degree of parasitization by *A. mali* on the check and DNC-oil emulsion treatments and only slight parasitization where DDT and BHC had been used.

There was no tainting detectable in fruit harvested from BHC sprayed trees.

1949-50 Season

Applications of BHC and parathion with and without the addition of winter oil were made in the dormant season to trees of the variety Cox's Orange Pippin. Results given in Table VI show that BHC treatments again gave a marked reduction in woolly-aphis infestation, the higher dosage rate of 10 oz gamma isomer to 100 gal water being the more effective. The addition of winter oil to BHC gave improved control, but the difference just failed to reach significance at the 5 per cent level. Parathion, at both dosage rates, gave improved control compared with the check. The addition of winter oil to the higher dosage of parathion failed to show any improvement in control, whilst at the lower dosage rate addition of winter oil caused a significant increase in woolly-aphis infestation.

In the harvested crop no tainting by BHC could be detected.

TABLE VI. DORMANT APPLICATIONS OF BHC, PARATHION AND WINTER OIL ON VARIETY COX'S ORANGE PIPPIN FOR CONTROL OF WOOLLY-APHIS; SEASON 1949/50

*Treatment No.	Concentration of Spray in 100 gal. water	Shoots infested 25 May		Woolly-aphis infestation observed 13 Feb.
		Percentage	Equivalent angle	
1	Gamma BHC 10-oz.	14.0	21.0	very slight
2	Gamma BHC 5-oz.	32.0	34.2	slight
3	Gamma BHC 5-oz. plus winter oil 2-gal.	21.0	27.1	slight
4	Parathion 9.6-oz.	26.5	30.4	slight
5	Parathion 2.4-oz.	45.0	42.1	slight
6	Parathion 9.6-oz. plus winter oil 4-gal.	28.0	31.8	slight
7	Parathion 2.4-oz. plus winter oil 4-gal.	73.0	60.5	moderate
8	Check - no spray	83.0	65.9	moderate
	Difference for significance at 5%		11.8	

* (Treatments 1 to 7 carried out on 1 Sept.)

1949-50 Season

Applications of parathion, BHC and DDT plus summer oil were made to trees of the variety Dunn's Favourite. Woolly-aphis infestation was very light and consequently the method of recording used in previous seasons was abandoned in favour of counting the total number of infested twigs observed on each tree up to a height of 7 ft. Because of differences in tree size these records are not as accurate as those obtained by the standard method.

Results shown in Table VII indicate that BHC applied immediately after petal-fall was the only treatment which showed a significant reduction in infestation compared with check. Parathion at both dosage rates gave results inferior to BHC but differences were not significant. Increased infestation of woolly-aphis occurred on trees receiving DDT plus summer oil, but as compared with the check treatment the difference was not significant.

The BHC formulation used in this trial was prepared from a purified chemical containing 99 per cent gamma isomer of BHC. Flavour tests by six independent judges on raw and cooked fruit at harvest time failed to reveal any indication of taint.

TABLE VII. SUMMER APPLICATIONS OF PARATHION, DDT AND BHC ON VARIETY DUNN'S FAVOURITE FOR CONTROL OF WOOLLY-APHIS: 1949-50 SEASON

Treatment No.	Concentration of spray in 100 gal. water	Date of applications	Shoots infested * 22 May
1	Parathion 1.2-oz	17 & 31 Oct.	10.0
2	" 2.4-oz	" " "	7.6
3	" 1.2-oz	20 Dec. & 13 Jan.	4.8
4	" 2.4-oz	" " "	6.0
5	DDT 1-lb plus summer oil 1-gal	13 Jan.	16.6
6	Gamma BHC 4-oz	17 & 31 Oct.	2.4
7	Check - no spray	---	11.6
	Difference for significance at 5%		7.1

* Because of light infestation the normal sampling method was not used; instead all new growths up to a height of 7 ft which showed infestation, were counted. The record shows mean number of infestations per tree. In Treatment 6 a wettable powder was used in which the BHC contained 99 per cent gamma isomer.

1949-50 Season

BHC sprays in which 99 per cent of the BHC was present as gamma isomer were applied to trees of the varieties Jonathan, Dunn's Favourite and Cox's Orange Pippin, at various intervals during the summer. At harvest time the raw and cooked fruit was tested for the presence of abnormal flavours. In no case could tainting be detected even in a sample taken from trees which, three weeks earlier, had been sprayed at a dosage rate of 4 oz gamma BHC to 100 gal water.

DISCUSSION

Results of the experiments described leave little doubt that BHC is a highly effective spray treatment for control of woolly-aphis. In practice, however, it is found that severe tainting of the harvested crop may develop from the use of sprays formulated with technical BHC when applied in the growing season. This can occur even when several months elapse between time of spraying and fruit harvest. The experiments show that by applying BHC in the dormant season tainting of fruit can

be avoided. To secure reasonable control throughout the summer, a dosage rate of approximately 10 oz gamma BHC to 100 gal water is required whereas 4 oz is sufficient when applied during the growing period.

From one season's trials, it is apparent that the use of BHC sprays formulated from the purified chemical containing 98 per cent gamma isomer may provide a means of avoiding the tainting associated with the mixed isomers of BHC. Such materials would have the added advantage that applications could be delayed until infestation commenced to develop, and in seasons of light infestation could be entirely omitted from the spray programme.

The evidence presented supports the view that use of DDT sprays leads to increased infestation by woolly-aphis. In all cases where DDT was used parasitization by *A. mali* was reduced but not eradicated. The effect of such sprays under conditions which pertain in commercial orchards cannot be judged from small plot trials since in the latter there is ample opportunity for re-establishment of the parasite from adjacent trees of the main orchard blocks. Observations, however, have been taken in several commercial orchards where two or more sprays of DDT have been applied and in all cases almost complete parasitization by *A. mali* has been found in the late autumn.

Where BHC is used, reduced parasitization by *A. mali* is also apparent. In this case, however, the eradication of woolly-aphis itself is an equally potent factor leading to reduction of *A. mali* populations.

DDD is highly toxic to *A. mali* but under conditions of normal orchard spraying does not kill woolly-aphis and in consequence increased infestations of woolly-aphis are likely to follow the use of this material.

From the one trial in which DNC-oil emulsion was used, results do not encourage any hope of this treatment being of value in woolly-aphis control. Similarly the addition of winter-oil to BHC and parathion appears to be of little practical advantage. In one instance the addition of winter oil to parathion reduced the efficiency of control. This result was unexpected and requires confirmation before it can be accepted as an established fact.

Parathion as a dormant spray gave partial control of woolly-aphis but results suggest that excessively high dosage rates would be required to give results comparable with BHC. At such levels parathion would be a serious toxic hazard to operators. Similar results secured with summer sprays of parathion indicate that this material is unlikely to be as effective as BHC for woolly-aphis control.

CONTROL OF THE GRAPEHOUSE MEALYBUG (*Pseudococcus maritimus* Ehr.)

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(*Received for publication, 24 December 1951*)

Summary

During winter in Auckland, the grapehouse mealybug, *Pseudococcus maritimus* Ehr. is not in a resting condition on grape-vines under glass.

Fumigation with hydrocyanic acid gas close to bud-burst period, using Cyanogas "G" Fumigant at 3 lb per 1,000 cu ft of space resulted in control of mealybug but caused severe damage to vines.

Sprays of 1* or 3 per cent DDT applied to dormant vines without any subsequent treatment did not result in completely uninfested fruit bunches at harvest. Dormant sprays containing 0·05, 0·1 or 0·5 per cent DDT followed by dusts of 1, 2 or 5 per cent DDT respectively, produced clean fruit at harvest. Dusts of 1 and 5 per cent DDT applied to vines in foliage gave control. Sprays of 0·1 and 1·0 per cent DDT applied to vines during the growing period damaged foliage and fruit. Benzene hexachloride sprays at 0·1 per cent and dusts at 0·5, 1·0 and 5·0 per cent concentration of crude BHC containing 12½ per cent γ isomer caused plant damage and gave poor control of mealybug except an emulsion containing 0·1 per cent crude BHC. Nicotine sulphate gave poor results and damaged fruit.

Three applications of 5 per cent DDT dust up to fruit-thinning period did not result in residues on fruit above the tolerance level.

The treatment recommended is a dormant application of 1 per cent DDT spray followed by summer applications of 2 per cent DDT dust up to the fruit-thinning period.

Introduction

The present paper describes experimental work carried out at this Division on control of the grapehouse mealybug *Pseudococcus maritimus* Ehr. At the time the work was begun the grower of grapes under glass had to spend much of his time in the dormant season cleaning and brushing the vines and then painting them with a preparation containing clay and tar or other materials. However, the control obtained in this way, even though it entailed a great deal of tedious labour, was rather indifferent, and it was found necessary to follow up in the summer with sprays such as nicotine sulphate, or fumigation with hydrocyanic acid gas. The work detailed below describes how it has been found that the mealybug can be checked very efficiently with DDT sprays and dusts. The time used in the application of these is only a fraction of that previously required for control measures, and there is no doubt that this new method is a great advance on those available hitherto.

Experimental Procedure and Results

Investigation of the Overwintering Habits of the Mealybug

In Auckland grapehouses during the winter, the mealybug can be found in all stages on the vine. Colonies are present under pieces of loose bark or clustered round the nodes. It would appear that the insect derives nourishment by sucking sap through thin places in the bark, particularly where this is cracked and oozing sap. In order to discover whether or not the many eggs that are present on the vines

* All percentages of DDT in this paper refer to para para isomer content.

at this time are in a state of hibernation, samples were collected on 10, 17 and 29 July 1944, and kept under observation. They were placed in lots of approximately 100 in containers consisting of the lower halves of petri dishes provided with muslin covers. These containers were kept in the grapehouse. In each sample of 700 to 1200, 80 to 100 per cent of the eggs hatched within two weeks.

It is clear therefore, that the eggs were not hibernating. These observations, together with the fact that the insects were present in all stages of development, showed that at no stage was the insect in a resting condition.

Winter Fumigation Tests—1944-45

In the past it has been the practice in many cases to fumigate with hydrocyanic acid gas during the summer when the vines were in foliage, but it often happened that on windy nights air movement led to heavy concentration of the gas and severe damage at one end of the house. When it was discovered that the mealybug did not appear to have any hibernating stage and would probably be just as vulnerable in winter as in summer, it was thought that a heavier winter fumigation would probably give an extremely good kill of the insect without damage to the dormant vines. Accordingly it was decided to test this idea.

A grapehouse, of 12,775 cu ft capacity, was made as airtight as possible and fumigated with Cyanogas " G " at the heavy rate of approximately 3 lb per 1,000 cu ft. The fumigation proceeded from 4.30 p.m. on 13/8/44 to 4.30 p.m. on 15/8/44. At this time one or two buds were showing signs of swelling.

It was considered that the eggs would be the most resistant stage, and in order to test the effect of the treatment, approximately 1,000 eggs were collected from the vines on 17 and 21/8/44 and kept under observation in petri-dish containers with muslin covers as described above. They were compared with approximately 1,000 eggs collected on 13/8/44 before fumigation, 90 per cent of which had hatched by 2/10/44. None of the fumigated eggs had hatched by 16/10/45.

Although no live mealybug could be found, it was clear, however, at this time, that severe damage had been done to the vines as none of the buds had burst, and on 9/1/45 it was discovered that all rods inside the house were dead. The vines were then cut back to the point of entry into the house to allow new growth to develop.

This experiment demonstrated that this concentration of hydrocyanic acid gas, used for 48 hr at the particular time of treatment was excessive.

No further work was done on winter fumigation with hydrocyanic acid gas.

Tests with Sprays—1945-46

By 15/11/45, the vines had grown again sufficiently to allow further experiments to be made. Infestation had apparently re-entered from the basal portions of the vines outside the house where mealybug was present.

Benzene hexachloride, DDT and nicotine sulphate sprays were used as follows:—

(1) 0·1 per cent DDT : made by using 0·2 lb of a preparation containing 10 per cent DDT on pyrophyllite plus 1·7 g Agral L (wetting agent) to 2 gal of water.

(2) 0·1 per cent DDT emulsion : made by adding 22·7 g naphtha " Wetsit " 20 per cent DDT miscible oil to 1 gal of water.

(3) 0·1 per cent benzene hexachloride : made by using 0·1 lb of a preparation containing 20 per cent benzene hexachloride (12½ per cent γ isomer) on pyrophyllite plus 1·7 g Agral L to 2 gal water.

(4) 0·1 per cent benzene hexachloride emulsion spray : made by adding 30 g of a mayonnaise emulsion containing 15 per cent benzene hexachloride (12½ per cent γ isomer) to 1 gal of water ; the emulsion, as well as benzene hexachloride, contained an aromatic solvent, casein-borax emulsifier, paraffin oil and yellow petrolatum.

(5) Nicotine sulphate, 1 part in 600 parts of water plus soft soap 3 lb in 100 gal.

The house contained 24 vines and treatments were randomized. Six vines were used for Treatments 1 and 5, five for Treatment 3, and since it was anticipated that the oil preparations would cause plant damage, only one for Treatments 2 and 4. The controls, consisting of five vines, were sprayed with water only. There was only one application, this being made on 15/11/45. At this time the vines were in full foliage and the bunches of berries were small.

Thinning of the fruit bunches was carried out from 10/11/45 to 3 12 45.

Bunches of grapes, harvested in February, were inspected and classified into those without, and those with, mealybug infestation. Results are shown in Table I.

Table I. Results of Spray Treatments for Control of Grapehouse Mealybug · 1945-46 Season

Treatment	Mean percentages uninfested fruit bunches per vine	Equivalent angles
0·1% DDT spray	96·9	84·8°
0·1% DDT emulsion	100*	—
0·1% benzene hexachloride spray	52·2	47·0°
0·1% benzene hexachloride emulsion	92·3*	—
Nicotine sulphate 1-600 plus soft soap 3 lb per 100 gallons	72·4	65·0°
Control	73·1	63·3°
Difference required for significance at 5% level		23·5°

* Observations made on one vine only.

The berries were also inspected for russetting and the vines for leaf injury, with the following results :—

(1) 0·1 per cent DDT spray : Four of the six vines had some leaves showing brown spotting ; many of the fruit bunches had russetted berries.

(2) 0·1 per cent DDT emulsion : The single vine in this treatment showed a considerable amount of foliage injury ; fruit bunches had many russetted berries, some being badly damaged.

(3) 0·1 per cent benzene hexachloride : On three of the five vines some leaves were spotted brown ; many of the fruit bunches had russetted berries.

(4) 0·1 per cent benzene hexachloride emulsion : The single vine in this treatment showed foliage injury with many of the young leaves burnt ; all fruit bunches had badly russetted berries.

(5) Nicotine sulphate plus soft soap : All six vines had foliage uninjured ; fruit bunches had many russetted berries, many of which also showed black scars.

(6) Control : Foliage on all vines was uninjured ; a few of the fruit bunches had some russetted berries.

Inspection of Table I shows that at the 5 per cent level no treatment gave a significant increase of uninfested fruit bunches over the check although the 0·1 per cent DDT spray almost satisfied this condition. All sprays injured the foliage or fruit in varying degrees. The emulsions of DDT and benzene hexachloride were especially harmful.

Tests with Dusts and a DDT Spray—1946-47

After the previous year's experience it was decided that, if possible, spray treatment should be avoided because of damage to fruit and foliage. Therefore, in the season 1946-47, several dust treatments were tried, and only one spray. Treatments were: 1 per cent DDT dust ; 5 per cent DDT dust ; 1 per cent benzene hexachloride dust ; 5 per cent benzene hexachloride dust (reduced to 0·5 per cent dust after one application); 1 per cent DDT spray.

The DDT dusts were made from 10 per cent DDT dust and talc ; the benzene hexachloride dusts were made from crude benzene hexachloride containing $12\frac{1}{2}$ per cent γ isomer and talc ; the 1 per cent DDT spray was prepared from 10 per cent DDT dust plus Agral L.

TABLE II. RESULTS OF SPRAY AND DUST TREATMENTS FOR CONTROL OF GRAPEHOUSE MEALYBUG : 1946-47 SEASON

(Counts of mealybugs on lower 6 ft of vine on 4/12/46 : four vines per treatment.)

Treatment	Mean no. mealybugs per vine	Mean log (n + 1)
1% DDT dust	69	1·81
5% DDT dust	40	1·58
1% benzene hexachloride dust	29	1·47
5% (0·5%) benzene hexachloride dust	44	1·61
1% DDT spray	0	0
Control	108	2·03
Difference required for significance at 5% level		0·26
,, ,, ,, ,, ,, 1% ,,		0·35

TABLE III. RESULTS OF DUST AND SPRAY TREATMENTS FOR CONTROL OF GRAPEHOUSE MEALYBUG: 1946-47 SEASON

(Percentage of uninfested fruit bunches at harvest: four vines per treatment.)

Treatment	Total no. fruit bunches harvested	Mean % clean bunches per vine	Equivalent angles
1% DDT dust	85	78·8	63·1°
5% DDT dust	75	100	90·0°
1% benzene hexachloride dust	84	38·1	37·7°
5% (0·5%) benzene hexachloride dust	57	10·5	16·2°
1% DDT spray	9*	100	90·0°
Control	89	34·8	35·1°
Difference required for significance at 5% level			18·5°
,, ,, ,, ,, ,, 1% ,,			25·9°

* Most of fruit removed before harvest to allow vine to recover from injury caused by treatment.

Applications were made on 18/9/46, 9/10/46, 31/10/46 and 24/11/46. On 18/9/46 the dusts were used at the rate of approximately 1 oz and the spray 2 pt per 12 ft of vine. Because of damage resulting from the first application, the 5 per cent benzene hexachloride dust was subsequently reduced to contain only 0·5 per cent benzene hexachloride. On 9/10/46, all dusts were applied at the rate of approximately 1 oz and the spray at $3\frac{1}{2}$ pt per 12 ft of vine. Because of damage from the first two applications, no further treatments were made with 1 per cent DDT spray. On 31/10/46 the dusts were used at $1\frac{1}{2}$ oz, and on 24/11/46 at $1\frac{3}{4}$ oz per 12 ft of vine. Of the 24 vines in the house, four were used for each treatment and four were kept as controls. The treatments and controls were randomized. Thinning of the fruit bunches was carried out from 12/11/46 to 29/11/46. On 4/12/46, a count of mealybugs was made on the lower 6 ft of each vine starting 1 ft from the point of entry into the house. All stages of mealybugs except the eggs were included in the count. Results are shown in Table II.

Inspection of Table II shows that the 1 per cent DDT spray was easily the most effective treatment in preventing development of mealybug on the vines.

As far as freedom of the fruit from infestation was concerned, (Table III), the best treatments were 5 per cent DDT dust and 1 per cent DDT spray.

During February 1947, the fruit bunches were harvested and sorted into those uninfested and infested with mealybug. Results are shown in Table III.

Observations on damage to vines were as follows:—

(1) 1 per cent DDT dust: No damage.

(2) 5 per cent DDT dust: No damage.

(3) 1 per cent benzene hexachloride dust: The foliage was slightly damaged.

(4) 5 per cent benzene hexachloride dust: On 19/9/46, the day after the first application, considerable burning of the young shoots was evident, and by 30/9/46 these shoots were quite black and seemed to be damaged beyond recovery. In the next and all subsequent applications, the benzene hexachloride content was reduced to 0·5 per cent and the vines recovered so markedly that they were allowed to carry a crop of fruit.

(5) 1 per cent DDT spray: Leaf scorch was evident on the day after the first application. By 24/10/46, the leaves had developed a mottled appearance, had become curled and had a characteristically hard texture (Fig. 1). These symptoms increased markedly and on 22/11/46 the vines were so debilitated that most of the fruit was removed to allow them to recover. Because of this damage, only two applications of the spray were made, viz. on 18/9/46 and 9/10/46

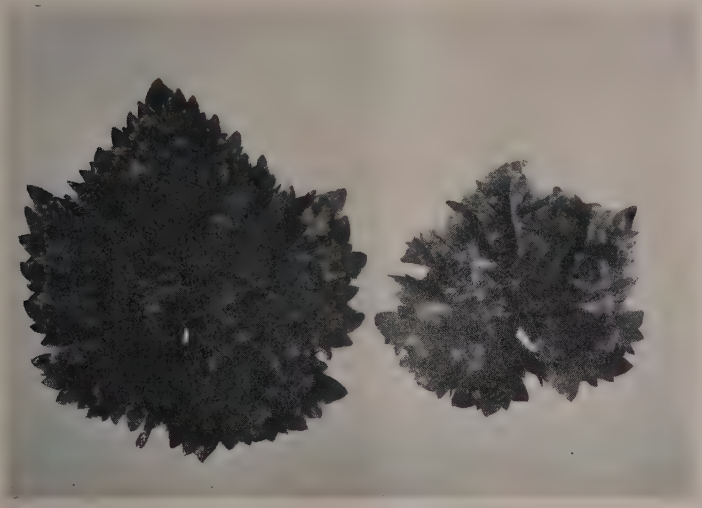

FIG. 1.—Mottled appearance of grape leaves caused by 1 per cent DDT spray applied to foliage

DDT Residues on Fruit: On 19/2/47, one bunch of grapes was taken at random from each of the four vines treated with four applications of 5 per cent DDT dust. Analysis for DDT residues showed that on three of the bunches there was a residue of DDT of less than 1 part per million (p.p.m.) of fruit, while on the fourth there was only a trace, probably less than 0·1 p.p.m. The residues were thus well within the tolerance limit of 7 p.p.m.

Tests with DDT Spray and Dust—1947-48

After considering the results of the previous season it was decided to use only DDT in season 1947-48. Owing to the damage that occurred in previous experiments, it was considered advisable to limit the 1 per cent DDT spray to a single application before budburst. The only other treatment used was a 5 per cent DDT dust. The 1 per cent DDT spray was prepared by using $\frac{1}{2}$ lb 50 per cent DDT wettable powder in $2\frac{1}{2}$

gal of water and was applied on 25/8/47, 2 gal being used on 6 vines, each of which was approximately 12 ft long. The 5 per cent DDT dust was prepared by mixing 5 oz of 10 per cent DDT with 5 oz magnesite-talc, using 5 oz of the mixture on 8 vines each approximately 12 ft long. The first application of dust was made on 19/9/47, when most of the foliage shoots were 3-4 in. long with an occasional flower panicle here and there. Three more applications were made, viz. on 10/10/47, 4/11/47 and 26/11/47, in which 9, $5\frac{1}{4}$ and $9\frac{1}{2}$ oz respectively were used per 8 vines. Treatments were randomized.

Thinning of the fruit bunches was carried out from 3/11/47 to 21/11/47.

On 26/11/47 counts for mealybug were made on the lower 6 ft of each vine. Results are shown in Table IV.

TABLE IV. RESULTS OF SPRAY AND DUST TREATMENTS FOR CONTROL OF GRAPEHOUSE MEALYBUG: 1947-48 SEASON

(Numbers of mealybugs on lower 6 ft of vines: eight vines per treatment.)

Treatment	Mean no. mealybugs per vine	Mean log (n + 1)	Mean no. egg masses per vine	Mean log (n + 1)
1% DDT spray	6	0·75	2	0·44
5% DDT dust	11	0·83	11	0·84
Control	56	1·62	45	1·44
Difference required for significance at 5% level		0·47		0·47
Difference required for significance at 1% level		0·63		0·63

In February 1948 the fruit bunches were harvested and examined for mealybug infestation. Results are shown in Table V.

TABLE V. RESULTS OF SPRAY AND DUST TREATMENTS FOR CONTROL OF GRAPEHOUSE MEALYBUG: 1947-48 SEASON

(Percentage of uninfested fruit bunches at harvest: eight vines per treatment.)

Treatment	Mean % uninfested fruit bunches per vine	Equivalent angles	Total weight of fruit harvested (lb)
1% DDT spray	77·9	63·8°	246
5% DDT dust	93·4	79·0°	234
Control	16·9	17·7°	201
Difference required for significance at 5% level		17·9°	
Difference required for significance at 1% level		24·3°	

The 1 per cent DDT spray caused no damage to the vines. On 14/10/47, after two applications, it was seen that on several of the vines treated with 5 per cent DDT dust the leaves from the earliest-bursting buds showed signs of distortion and mottling similar to that shown by the vines sprayed with 1 per cent DDT in the 1946-47 season (cf. Fig. 1). It would seem, therefore, that the leaf curling and mottling was caused by the first dusting rather than by the subsequent applications. There was no reduction in the weight of fruit borne by these vines, and all fruit was in excellent condition.

Although results of this season's work suggested that the four applications of 5 per cent DDT dust during the growing season gave better mealybug control than did the one application of 1 per cent DDT spray before the buds burst, the differences were not significant at the 5 per cent level.

Tests with DDT Sprays during Dormant Period—1948-49

This season's work was devoted to determining whether applications of DDT spray in the dormant season before the buds burst would give sufficient control of mealybug throughout the growing period of the crop. Sprays containing 1 and 3 per cent DDT were each used as single and double applications. All sprays were prepared from a 50 per cent DDT wettable powder. The 24 vines in the house were divided into eight lots of three adjacent vines. In order to prevent spread of mealybug from untreated to treated vines, no control was kept. The treatments were randomized among the eight lots, two lots of three being used for each treatment. The first application of both concentrations was made to all vines on 12/7/48, and a second application was made to 12 of these on 20/8/48. At each application, approximately one-third of a gallon was used per vine 12 ft long.

Thinning of the fruit bunches was carried out from 2/11/48 to 19/11/48.

The fruit was harvested in February 1949 with results shown in Table VI.

Table VI. Results of Dormant Sprays of DDT for Control of Grapehouse Mealybug: 1948-49 Season

(Percentage of uninfested fruit bunches at harvest: 6 vines per treatment.)

Treatment	Mean % uninfested fruit bunches per vine	Equivalent angles
1% DDT spray. 1 application	53·4	47·1°
1% DDT spray. 2 applications	66·0	55·5°
3% DDT spray. 1 application	79·9	66·6°
3% DDT spray. 2 applications	89·0	74·3°
Difference required for significance at 5% level		15·0°
„ „ „ „ „ 1% „		20·7°

These results show that one spray of 1 per cent DDT resulted in little more than half the crop being completely clean. The percentage of clean bunches progressively increased to almost 90 per cent with two sprays of 1 per cent, one spray of 3 per cent and two sprays of 3 per cent DDT respectively.

Tests with Combination of DDT Spray and Dust—1950-51

In this final season, three combinations of DDT spray in the dormant period followed by DDT dusts during the growing period were tested. The combinations were :

(1) Dormant spray containing 0·5 per cent DDT : made by mixing 2 lb of " D " Spray powder, which contained 25 per cent DDT, in 10 gal of water. It was followed by three applications of dust containing 5 per cent DDT dust.

(2) Dormant spray containing 0·1 per cent DDT : made by mixing 2 lb " D " Spray powder containing 25 per cent DDT in 50 gal of water ; it was followed by three applications of " D Dust No. 2 " containing 2 per cent DDT.

(3) Dormant spray containing 0·05 per cent DDT : made by mixing 2 lb of " D Spray " containing 25 per cent DDT in 100 gal of water ; it was followed by three applications of " D Dust No. 1 " containing 1 per cent DDT.

Of the 24 vines in the house, 6 were used for each of the above treatments and the control. Treatment and control vines were randomized throughout the house.

The dormant sprays were applied on 25/8/50, and the dusts on 17/10/50, 3/11/50 and 24/11/50. The sprays were used at approximately one-third gallon and the dusts at approximately $1\frac{1}{4}$ oz per 12 ft of vine.

Thinning of the fruit bunches was carried out from 2/11/50 to 16/11/50.

The fruit was harvested in February 1951 and the bunches were classified into those uninfested and those infested by mealybug. Results are shown in Table VII.

TABLE VII. RESULTS OF COMBINATION OF SPRAY AND DUST TREATMENT FOR CONTROL OF GRAPEHOUSE MEALYBUG, 1950-51 SEASON.

(Percentage of uninfested fruit bunches at harvest: 6 vines per treatment.)

Treatment	Mean percentage of uninfested fruit bunches per vine	Equivalent Angles
0.5% DDT spray plus 3 applications of 5% DDT dust.	97.0	82.9°
0.1% DDT spray plus 3 applications of 2% DDT dust.	91.9	75.9°
0.05% DDT spray plus 3 applications of 1% DDT dust.	92.4	76.2°
Control	32.3	31.0°
Difference required for significance at 5% level		17.3°
" " " " " 1% "		23.6°

It is clear from these results that although the 0·5 per cent DDT spray followed by 5 per cent DDT dusts gave the highest mean percentage of uninfested fruit bunches, there was no significant difference at the 5 per cent level between any of the treatments. Each gave a much greater yield of uninfested fruit bunches than did the control. There was no damage to fruit or foliage by any of the treatments.

DISCUSSION

The fact that, in Auckland at least, the grape mealybug *P. maritimus* Ehr. does not have any definite hibernating stage has opened up certain possibilities for control. Probably a smaller dosage of hydrocyanic acid gas than that used would have given satisfactory control of mealybug without serious plant damage. However, since the work described in this paper has resulted in the discovery of a satisfactory control that is simpler and much less dangerous to both operator and vines, there is at present no reason for experimenting further with this gas. The better understanding of the overwintering habits of the mealybug, and the damage to leaves and fruit from the use of 0·1-1·0 per cent DDT sprays after bud-burst, prompted the use of DDT on vines in the dormant period. Apart from this damage, which was severe with the higher concentration, 0·1 and 1·0 per cent DDT sprays gave reasonably good control of mealybug infestation (Tables I-III). After 1946-47, DDT spray was applied in the dormant period only, the concentration, until 1950-51, being kept at 1 per cent in the hope both of killing mealybug on the vines at this stage and of providing a residue that might remain effective for a considerable time. The use of this spray, once only, before bud-burst resulted in considerable control (Tables IV and V), although the condition of the fruit at harvest was still not satisfactory, approximately 22 per cent of the fruit bunches showing mealybug infestation (Table V). Even dormant treatment with 3 per cent DDT (Table VI) did not result in a completely clean crop. This is not altogether surprising as the sphere of action of the DDT can lie only on the main stem of the vine, and once laterals and foliage have become well grown and have been infested by a few mealybugs, there is no DDT in such positions to stop their development.

DDT dusts gave good results when applied to the vines in foliage. Table III shows that 5 per cent dust gave 100 per cent, and 1 per cent dust approximately 79 per cent uninfested fruit bunches at harvest. This was confirmed for the 5 per cent dust in the following season when four applications produced approximately 93 per cent uninfested fruit bunches (Table V).

When the combination of one dormant DDT spray and several DDT dustings is considered (Table VII), it appears that the dormant spray can be reduced to 0·05 per cent DDT content, and the dusts to 1 per cent DDT content. It is considered, however, that a certain amount of caution should be used in accepting these figures as they are derived from one season's work only. Nevertheless, they indicate that the dormant spray could probably be reduced below 1 per cent DDT content and the dusts below 5 per cent DDT content without causing significant loss of crop. It also brings into question the significance of the dormant applications in the combination. For example, are the foliage applications of dust alone sufficient to produce clean crops ? Unfortunately this cannot be answered from the work carried out to date, but for two reasons it is considered that dusts should be kept to a minimum. The

first is the possibility of exceeding the residue tolerance of 7 p.p.m. The work on residues, reported under season 1946-47, indicates that provided dusts are applied carefully at the rates mentioned and not later than the fruit-thinning period, there are unlikely to be excessive residues at harvest. However, special care must be taken to make applications evenly and thinly. Careless work will result in excess of dust on some fruit bunches, and these excesses are likely to be more frequent with increasing number of applications. The second reason is that too much DDT applied to the foliage will result in increased populations of red spider (*Tetranychus* spp.). For these reasons, it would seem that it is best to aim at securing as much control as possible with the dormant spray and to use dusts on the foliage as sparingly as possible. In the absence of data on minimum effective dosages, it is suggested that the basis of the treatment for mealybug be the application of the 1 per cent DDT dormant spray, which in 1948-49 gave by itself only a little over 50 per cent uninfested fruit bunches, followed as sparingly as possible by 2 per cent DDT dusts. After a season or two when the mealybug population has been greatly reduced, it may be found that only the dormant spray and one dusting are required.

The benzene hexachloride sprays and dusts damaged plants and, except for 0·1 per cent emulsion used in 1945-46, gave poor control of fruit infestation (Tables I and III).

Nicotine sulphate did not materially reduce infestation of fruit bunches at harvest (Table I). It also damaged the fruit

Since experience in these trials has shown that almost any spray material applied to the vines in foliage is likely to damage the fruit, it is considered that sprays should, if possible, be avoided after bud-burst.

One final point noted in this work was that where mealybug had been eliminated from a house, such as occurred in the cyanide fumigation in 1944-45, re-infestation occurred from those portions of the vines outside the house. Therefore, where vines are rooted outside and led in through the walls, it is wise to treat also those portions exterior to the house.

Conclusions

(1) In the grapehouse, mealybug can be successfully controlled by DDT.

(2) Pending further work on minimum effective dosages, it is considered that the following programme will give good control: An application of 1 per cent DDT spray to the vines during the dormant season as near as possible to bud-burst period, followed by one or more treatments with 2 per cent DDT dust as required, but no dusting to be made after the thinning period. Because of possible harmful residues, the number of dustings should be kept to a minimum.

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FROST DAMAGE TO APRICOT BLOSSOMS AND FRUIT

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Summary

Blossom and small fruits of the apricot varieties Moorpark and Roxburgh Red were frozen artificially during four seasons to determine the point at which damage occurred. Although there were wide variations between replications it was demonstrated that flowers of both varieties became more susceptible to frost as they developed. In general, amount of damage increased with increase in time of exposure to a given temperature.

Measurements of temperature inside flowers on the tree during a frost showed that there was little variation from air temperature. Percentage damage for a given temperature was much greater for wet blossom than for dry. There was some evidence to suggest that flowers borne on wood three or more years old were more susceptible to frost than flowers carried on one year old wood. When flowers or fruit were held for periods of an hour or more at a temperature known to cause damage and then cooled quickly a further 1°F., percentage damage was increased, but only to a moderate degree.

Lists of critical temperatures for various stages of growth are given. By lighting orchard heaters at the times indicated, a full crop was secured from a block of 60 trees for two successive seasons.

Introduction

Spring frosts cause damage to economic crops throughout the temperate zones of the world and have played a large part in fixing limits for various crops. As no cheap method has yet been devised for controlling frost, normal practice is to grow deciduous fruits in areas comparatively free from spring frost. In some localities, combinations of suitable soil, good summer climate and freedom from disease have induced growers to accept the frost risk, and orchards have been established. Central Otago is an area of this type where it has proved economic to adopt orchard heating as standard practice.

Growers having installed oil burning fire pots were faced with the problem of when to use them. Local observation and reports from overseas gave a rough guide to pioneers of this practice. As it is always difficult to tell, from field observation after a frost, at what temperature blossom or fruit was damaged, no clear picture of damaging temperatures had emerged during twenty years of frost fighting. Workers in North America have attempted to assess damaging temperatures mainly from field observations. Their published lists of temperatures considered dangerous to apricots at a particular stage of growth show variations of as much as 8°F. (Gardner *et al.*, 1939). An accurate knowledge of critical temperatures is of considerable practical importance. It is wasteful of oil to light before the danger point is reached, but if lighting is delayed beyond this point, serious loss of crop may follow. The experiments described below were undertaken to determine danger points for the two main apricot varieties grown in Central Otago. The provisional list of damaging temperatures based on two seasons' work published earlier (Atkinson, 1949) is superseded by figures given in the present paper.

Equipment and Methods

As observation of natural frost damage was not practicable artificial freezing was adopted. Several authors (West and Edlefsen, 1921; Field, 1939; Rogers and Modlibowska, 1950) have shown that this method will give damage closely approximating that occurring naturally.

It has been suggested (Gardner *et al.*, 1939) that critical temperatures decided by laboratory methods should be lower than those observed under field conditions because of differences assumed to exist between air temperatures and plant temperatures under radiation conditions. This assumption is not justified by observation of natural frost injury nor by the few published figures giving actual measurements of bud temperatures (Rogers and Modlibowska, 1950).

In an endeavour to simulate natural frost conditions, it was decided to attempt freezing blossom and young fruit while still on the tree. For this purpose the Dominion Physical Laboratory designed and built the equipment shown in the accompanying illustration (Fig. 1).

FIG. 1.—Equipment designed for artificial freezing of fruit blossom while on the tree.

(*Photo by National Publicity Studios*)

Its chief components were: an insulated canvas bag on a metal frame large enough to enclose part of a branch, a small refrigerator and fan. The Refrigerator unit and fan were connected to the bag by insulated hoses. Cooled air was blown into the bag at one end and withdrawn back to the cooling coil from the opposite end. Rate of flow through the bag was regulated to approximate that of the air drifts occurring under radiation conditions, about one mile per hour. A heater unit was included in a by-pass of the circuit to permit temperature to be held constant with the refrigerator working continuously. Temperatures inside the bag were measured by two alcohol thermometers visible through a small observation port. As bag temperature fell to within 0·5°F. of the required point, a small amount of warm air was allowed into the main stream by manual operation of a check valve. With a little practice it was possible to achieve practically steady temperatures within the bag. Greatest limitations of the equipment were

its small refrigerating capacity and relatively poor insulation made necessary by weight limitations. Temperatures inside the bag could be reduced only some 20°F. below ambient temperature. Thus experiments had to be carried out on cool nights.

During the first season's experiments, freezing was carried out on established apricot trees in the manner illustrated. It was a slow, clumsy process. Field (1939) had shown that detached apple blossom could be used satisfactorily for artificial freezing experiments, and trials were carried out with detached apricot laterals. It was found that flowers on these reacted in the same way as those still on the tree. In later seasons all experiments were carried out with detached twigs. As the limited capacity of the equipment prevented operation in warm periods that occur each spring, it was not possible to obtain continuous records in any year.

For each experiment, sufficient fruiting laterals at the same stage of development were collected to give a sample of about 100 flowers for each time-temperature combination to be tested. Laterals were mixed, divided into samples of equal size and placed loosely on wire netting shelves in the bag. Temperature was lowered as rapidly as possible from ambient temperatures of the order of 30° to 45°F. Rate of cooling varied with conditions but usually it ranged from 9° to 11°F. in the first 20 minutes, and thereafter slowed down progressively as the maximum capacity of the equipment was reached. During a typical experiment flowers were held at the required temperature for 30 minutes and then one sample was removed. Temperature inside the bag rose by 1° to 2°F. while this operation was carried out, but was rapidly brought back to the required point. Other samples were withdrawn at various intervals. After freezing, all flowers were thawed out at the prevailing air temperature, which was seldom above 45°F. for the first hour of thawing. Damage was usually clearly visible two hours after specimens were removed from the bag, but to permit all injured flowers to change colour, examinations were delayed until some eight hours after thawing began. Control samples collected at the same time as those frozen showed no wilting or other abnormality.

On almost every fruiting lateral used for this work there was appreciable variation in the rate of development of buds throughout its length. In general, basal flowers opened first, those at the tips last. When records were required of damage at full bloom, flowers that had reached petal fall and those not quite open were discarded. Of the remainder it is certain that some had been open for only a day, some for several days. Thus, although the flowers appeared to be all at one stage, there was an appreciable range of development within the group. There was similar variation within groups of buds that appeared all to be at one of the other stages of growth. As no rapid means was devised for determining which were the more advanced flowers, this variation had to be accepted.

Most experiments were carried out with flowers borne on the previous season's wood, but a small proportion of two- and three-year-old wood was used in some trials. Except in a few instances, detailed in Table V, wood of different ages was not kept separate.

On nights when dew formed, the bark showed a thin film of moisture, which probably also covered flowers, though not visible on the petals. No attempt was made to compare dry and dew covered flowers under the same conditions. Several trials were made in which flowers covered

by dew were frozen under the same conditions as similar flowers thoroughly wet from a spray of water. The percentage of wet flowers killed was much greater than that of flowers damp from dew, the order of difference being similar to that between wet and dry blossom. Thus, in all later experiments where specimens were damp with dew, this factor was disregarded and results grouped with those from dry flowers.

RESULTS

When results from each of four seasons were tabulated separately no differences attributable to season could be seen. Figures showing percentage damage from artificial freezing of Moorpark and Roxburgh Red apricots during the years 1948 to 1951 inclusive are grouped together and presented in Tables I and II.

There are large variations in the percentage of damage recorded for some time-temperature combinations at most stages of growth. It is thought that some of the factors which caused these variations were: variable age of blossoms that appeared to be all at one stage of growth; slight differences in moisture on the exterior of flowers; biological differences between trees; and experimental error. In spite of variations, two broad trends are shown. Firstly, that flowers of these two varieties become less resistant to frost as they develop, secondly, that the percentage damage increases as time of exposure to a critical temperature is lengthened.

At the foot of each table, danger points for each stage of growth are indicated. These are intended as a guide to fruitgrowers, and have been chosen on the assumption that with the normal heavy setting of apricots a loss of 5 per cent can be accepted for any one frost.

For the past two seasons a plot of 60 mature Moorpark apricot trees forming part of a larger block has been set aside for testing the value of these results under practical conditions. Oil pots in this plot were lit strictly in accordance with the list given, while pots in the remainder of the block were lit at the discretion of an experienced orchard manager. Nine frosts occurred during the spring of 1950, and two in that of 1951. On some occasions the experimental plot was lit before the main block, several times both were lit together, and twice the main block was lit 1½ hr ahead of the experimental plot. After each frost 100 blossoms or fruits were selected at random from each of the two areas and damage recorded. Maximum loss caused by a single frost in the test plot was 4 per cent. A good crop was secured on both areas in each of the two seasons. Although considerably more experience will be necessary before the limitations of the method are known, it appears that results secured by artificial freezing can be used as a basis for practical frost fighting.

FURTHER EXPERIMENTS AND RESULTS

Measurement of Bud Temperatures under Frost Conditions

To determine the internal temperature of apricot blossom under frost conditions, measurements were made in the field with sensitive thermo-couples. The junction of the couple that was to be inserted into buds was made by fusing one end of a piece of 40 S.W.G. constantan wire to a similar sized piece of copper, in such a way that they formed a continuous smooth wire. When in use, one end was pushed into the blossom and pulled through until the junction was inside the flower.

TABLE I. ARTIFICIAL FREEZING OF MOORPARK APRICOT FLOWERS AND FRUIT (DRY): COMBINED RESULTS OF SEASONS 1948, 1949, 1950, 1951. (All results are given as percentages of flowers or fruit frozen.)

		Stage of Development of Flowers or Fruit								
Temp. (°F.)	Duration (min.)	Pink	White Tip	Full Bloom	Petal Fall	Withered Stamens	Burst Calyx	Small Fruit 0.2-0.5 in.	Small Fruit 0.5-0.75 in.	Small Fruit 0.75-1.5 in.
23°	30	36								
	60	38,16, 7	22,20							
24°	30		63							
	60		64,24							
25°	10			2						
	30		3	35						
	60			20,69,74						
26°	15			6						
	30		11, 0, 0	0,20,29,15	24, 5					
	60		10, 0	58, 4,24,11, 3, 9,12	16					
	120		13	4,17,40, 9	20					
27°	30		4, 0	0, 0, 4,10, 0						
	60		0, 0	2, 0, 6, 1,11,11						
	120			9, 0						
	180		0, 1	10, 7, 6						
	210			1	16,42					
	240			7						
28°	20					0				
	30		0	0		0,10	0, 0	58		0,23
	45					9				
	60		0	0, 0		33, 0,13,50	3,29			1, 4
	120			0, 0	4		16			2
	180						22			30
	240						45			
29°	30				0, 1, 1	0, 0, 0	0, 4	12,24	2, 3	7
	60				0, 4, 0	0, 0, 0, 0	37, 0, 4	17,28,14, 1	4, 0,15	0
	120				8, 0, 0	0, 0, 0, 1		34,36	38,13	0,70,15,14
	180				0	4			75	91
	240									90
30°	30					0		16, 3,50, 0	9, 0	0, 0
	60					3, 0	0, 3, 1	0,22, 4, 9, 5	0, 0	5, 4, 2, 0
	120					5	0, 1	19,11,14		20, 2, 7,12
	240									14, 2
31°	30						0	0		64
	60						0	0		

Suggested lighting times based on data given above:

White tip	light at 26°F.				
Full Bloom	" " 26°F.	or after	27°	for	30 min.
Petal Fall	" " 27°F.	" "	28°	"	60 "
Withered Stamens	" " 28°F.	" "	29°	"	60 "
Burst Calyx	" " 29°F.	" "	30°	"	60 "
Small Green Fruit 0.2-0.5 in.	" " 30°F.	or when fruit shows mottling on surface.			

The other junction was housed in an aspirated radiation shield placed approximately one foot from the flower under test. A second thermocouple was set up with one end in the radiation shield and the other in melting ice. Temperature changes in both circuits were measured with a potentiometer. This equipment, provided by the Dominion Physical Laboratory, allowed direct comparison of bud and air temperature, and at the same time gave an accurate measurement of air temperature.

Five sets of readings were taken from flowers on the tree under natural frost, and three from flowers in the freezing apparatus. On each of these occasions air temperature was below freezing but did not reach damaging point for flowers under test. In general, flower temperature lagged slightly behind air temperature, the maximum difference between the two being 0·5°F. One set of readings from a flower on a tree is shown graphically in Fig. 2. Readings secured during artificial freezing were similar.

FIG. 2.—Measurements of temperature inside a Roxburgh Red apricot flower under natural frost conditions. No records were secured during the period 5 a.m. to 7 a.m.

Effect of Free Water on Flowers and Fruit under Freezing Conditions

Workers in England have reported that a greater percentage of wet apple flowers or fruit was damaged at a given temperature than was the case with comparable dry ones (Field, 1939; Rogers, 1949). To test the effect of similar conditions on apricot blossom and fruit two methods were used. As opportunity offered, samples wet from rain were collected and frozen; in these cases no comparable dry material was available. On other occasions a large sample of dry shoots was cut, divided into two, and half wetted by total immersion or by spraying with a hand pump. Wet and dry samples were then frozen under identical conditions. Detailed results for Moorpark and Roxburgh Red apricots are set out in Tables III and IV.

Where wet and dry material was frozen under identical conditions, the amount of damage was considerably greater in the wet sample in all but one case. When Tables III and IV are compared with Tables I and II, it is apparent that the presence of water on flowers or fruit raises the danger point by at least 1°F., possibly 2°F.

Effect of Age of Fruiting Wood on Frost Damage

To determine whether age of fruiting wood had any effect on susceptibility of flowers to frost injury, shoots of different ages were frozen under identical conditions. Results from the six trials are given in Table V.

TABLE II. ARTIFICIAL FREEZING OF ROXBURGH RED APRICOT FLOWERS AND FRUIT (DRY): COMBINED RESULTS OF SEASONS 1948, 1949, 1950, 1951 (all results are given as percentages of flowers or fruits frozen.)

Temp. (°F.)	Duration (min.)	Stage of Development of Flower or Fruit: Tiny	White Tip	Full Bloom	Petal Fall	Withered Stamens	Burst Calyx	Small Fruit 0.2-0.5 in. diam.	Small Fruit 0.5-0.75 in. diam.	Small Fruit 0.75-1.5 in. diam.
30°	5									
	60	14	17							
28°	60		0	8						
29°	15			4						
	30		0	1, 0	35					
	60			78, 4, 3*, 42, 1, 15						
	120			*, 6						
27°	30			0, 0						
	60			11*, 0, 0, 0						
	120			1, 10	,,					
	240			*, 2	93					
28°	30					0, 31	87, 69			
	60			4		56	96	44		
	120			0	40			62		
26°	10				0	22, 20, 4	0 ,	3	12	
	60				14, 1	5, 9, 1		0, 37	28, 19	5
	120				41	2, 7				5
30°	30					0		42, 0, 10, 3, 0	0, 7	
	60					0	13, 0, 9, 2	18, 26, 4, 0	0, 1	
	120						1	12	21	
31°	30					5	0	0, 0		
	60						0	0		
	120							0		
32°	60						0	0		
	120						0	0		

Suggested lighting times based on data given above:

Full Bloom	light at 27°F. or after 28° for 30 min.
Petal Fall	" " 29°F.
Withered Stamens	" " 29°F.
Burst Calyx	" " 30°F.
Small Fruit	" " 30°F. or when fruit shows surface mottling

TABLE III. EFFECT OF LOW TEMPERATURE ON DRY AND WET WOODPARK APRICOT BLOSSOM AND FRUIT
(All results expressed as percentage frozen.)

Temp. (°F.)	Duration (min.)	Stage of Development of Flowers or Fruit: White Tip Dry	White Tip Wet	Full Bloom Dry	Full Bloom Wet	Petal Fall Dry	Petal Fall Wet	Withered Stamens Dry	Withered Stamens Wet	Burst Calyx Dry	Burst Calyx Wet	Small Fruit 0.3-0.5 in. diam. Dry	Small Fruit 0.3-0.5 in. diam. Wet	Small Fruit 0.5-0.8 in. diam. Dry	Small Fruit 0.5-0.8 in. diam. Wet
24°	60	24	76												
25°	10			2	64										
26°	30					24	100								
	60			3	68										
27°	10			0	75										
	60			2	82										
	120			9	9										
	120			0	75										
	240			1	69	16	68								
28°	120			0	18										
29°	30					-	31								
	60							0	55				95	-	95
	120					0	81	0	80					0	100
30°	30									-	59				
	60							3	66	0	95	9	37	-	38
	60									-	96		50	-	27
	120									0	95				
	120									-	14				
31°	30					-	0					-	14	-	19
	60									-	23	-	12		

TABLE IV. EFFECT OF LOW TEMPERATURE ON DRY AND WET ROXBURGH RED APRICOT BLOSSOM AND FRUIT
(All results expressed as percentage frozen.)

Temp. (°F.)	Duration (min.)	Stage of Development of Flower or Fruit: Full Bloom Dry	Full Bloom Wet	Petal Fall Dry	Petal Fall Wet	Withered Stamens Dry	Withered Stamens Wet	Burst Calyx Dry	Burst Calyx Wet	Small Fruit 0.3-0.5 in. diam. Dry	Small Fruit 0.3-0.5 in. diam. Wet	Small Fruit 0.5-0.8 in. diam. Dry	Small Fruit 0.5-0.8 in. diam. Wet
25°	10	-	79										
26°	30			35	100								
	60	33	98	-	100								
	60	42	94										
27°	60	-	84	-	49								
	60	0	65										
	120	1	11										
	120	10	56										
	210	39	78										
28°	120	0	26										
29°	30			-	64								
	60					5	97	-	85	-	31	-	46
	120					7	82						
30°	30									10	49		
	60							13	78	-	100	-	68
	60									-	46	-	35
31°	30			-	0					-	10		
	60							-	23	-	69		
32°	60							0	37	0	7		

TABLE V. COMPARISON BETWEEN SUSCEPTIBILITY OF APRICOT FLOWERS TO FROST WHEN BORNE ON ONE-YEAR OLD OR [illegible] WOOD: SEASON 1949

Temp. (°F.)	Duration (min.)	Age of fruiting wood	Variety	Wet or Dry	Full Bloom	Petal Fall
27° 27°	210 210	1 year " "	Moorpark "	Dry "		16 42
27° 27°	210 210	1 year " "	Roxburgh Red " "	Dry "	39 [illegible]	
26° 26°	60 60	1 year old spurs	Moorpark "	Dry "	3 24	
26° 26°	60 60	1 year old spurs	Roxburgh Red " "	Dry "	33 42	
26° 26°	60 60	1 year old spurs	Roxburgh Red " "	Wet "	98 94	
(27° (26°	60 15	1 year	Roxburgh Red	Dry	39	
(27° (26°	60 15	3 year	" "	Dry	57	

These figures suggest that under dry conditions flowers borne on wood three or more years old are slightly more susceptible to frost injury than those borne on one-year-old wood.

Effect of a Sudden Drop of 1°F. *below Critical Temperatures*

Some field observations suggested that although flowers or young fruit were damaged in comparatively small numbers when the temperature remained steady at the critical point for some time, severe damage might occur if temperature dropped rapidly a further degree. The point is of importance to growers as it may take 30 minutes to light all pots. Results of trials to test this suggestion are given in Table VI.

TABLE VI. PERCENTAGE FLOWERS OR FRUIT OF MOORPARK APRICOT DAMAGED BY ARTIFICIAL FREEZING AT VARIOUS TIME-TEMPERATURE COMBINATIONS (DRY), 1949 and 1950 SEASONS

1st Temp. (°F.)	1st Time (min.)	2nd Temp. (°F.)	2nd Time (min.)	Full Bloom	Petal Fall	Withered Stamens	Small Fruit 0.2-0.5 in. diam.	Small Fruit 0.5-0.75 in. diam.	Small Fruit 0.75-1.5 in. diam.
(27° (27°	60 + 60	26°	15	0 0	9				
(29° (29°	180 + 180	28°	15		0	12 4			
(28° (28°	60 + 60	27°	30			40 33			
(29° (29°	120 + 120	28°	60			7 0			
(29° (29°	120 + 120	28°	60				46 36		
(29° (29°	120 + 120	28°	60				51 34		
(30° (30°	120 + 120	29°	30				38 14		
(30° (30°	120 + 120	29°	30				5 11		
(29° (29°	180 + 180	28°	30					82 75	
(30° (30° (30°	60 + 60 60	29° 29°	30 60						9 16 0
(30° (30° (30° (30°	120 + 120 + 120 + 120	28° 29° 29°	30 60 120						0 17 32 12

Note: No observations were made on flowers at the burst calyx stage.

Total exposure time could not be made comparable for each group of samples as only one set of equipment was available. No confirmation for the hypothesis was found. In all but two cases damage was greater where temperature was lowered a further degree at the end of the initial exposure period. Samples showing a greater damage had longer exposures, the extra time being at lower temperatures, but the amount of

damage that occurred is of the order to be expected from results given in Table I. There was no evidence to suggest that a temperature drop of 1°F. during the period that pots were being lit would cause severe loss.

DISCUSSION

Results secured during this series of experiments emphasise the variable amount of damage to apricots that is likely to follow any particular frost. While causes of this variation are still largely unknown, it seems that artificial freezing can be used to define dangerous temperatures with sufficient accuracy to be of practical use.

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BOOK REVIEW

LEAF ANALYSIS

By H. LUNDEGARDH, translated by R. L. Mitchell, 176 pp. with 63 tables and 32 figs. Hilger and Watts Ltd., London, 1951. Published price, 22/6.

This monograph was first published in Germany in 1945, and the authorized translation is taken from a manuscript revised in 1946. It is largely an account of work done at the Plant Physiology Institute, Uppsala-Ultuna, much of it being by Prof. Lundegardh himself, and by Dr. Burstrom. This work, which started as a theoretical study on nutrient uptake by roots, has led to the use of leaf analysis as a practical method for the determination of manurial requirements, mainly with cereals.

The first chapter, of 103 pages, deals with the physiological studies which led up to the leaf analysis method. The following subjects are discussed: the absorption of salts by roots, ion antagonism, the distribution of mineral matter in plants, the functions of roots and of leaves in relation to mineral distribution, the effect of nutrient level in the leaves on plant growth, and the effects of season, fertilization and partial drought upon the nutrient levels in the plant. This chapter would be adequate for workers in Europe for whom the original book was written; but from the point of view of a worker in New Zealand, it is all too brief. The full significance of much of the work cannot be appreciated without recourse to the original papers, and these are mainly in Swedish or German. Nevertheless, the chapter serves as a useful introduction to the series of interesting papers from Sweden on the uptake and movement of ions in plants, which have been published—largely in English—since 1946.

The second chapter describes the methods used in Sweden for the gathering and preparation of cereal leaf samples, and their analysis for phosphorus, nitrogen, potassium and calcium. The largely automatic spectrographic method for the determination of potassium and calcium is described in fair detail, and the author suggests that it may be possible to extend the method to include phosphorus, if arc or spark excitation can be perfected.

A final short chapter deals with the practical value of leaf analysis in the determination of manurial requirements. Quoting examples from surveys in Sweden, the author emphasizes his view that leaf analysis is a more dependable guide than soil analysis in this respect.

All those interested in plant nutrition would find useful information in this book, which serves the purpose of drawing attention to the work done in Sweden on the subject. The degree of condensation in the first chapter has, in places, made the book rather difficult to follow at a first reading. There are 169 references, many of them to Swedish and German work.

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